My precious! The location and diffusion of scientific research: evidence from the Synchrotron Diamond Light Source*

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ABSTRACT

We analyze the impact of the establishment of a GBP 380 million basic scientific research facility in the UK on the geographical distribution of related research. We investigate whether the siting of the Diamond Light Source, a 3rd generation synchrotron light source, in Oxfordshire induced a clustering of related research in its geographic proximity. To account for the potentially endogenous location choice of the synchrotron, we exploit the availability of a 'runner-up' site near Manchester. We use both academic publications and patent data to trace the geographical distribution of related knowledge and innovation. Our results suggest that the siting of the synchrotron in Oxfordshire created a highly localized cluster of related scientific research.

KEYWORDS: Synchrotron, location, innovation, patents

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1 Introduction

We investigate the impact of the establishment of a GBP 380 million scientific research facility in the UK on the geographical distribution of the knowledge created by the facility. The Diamond Light Source, a so-called 3rd generation synchrotron light source, represents the single largest investment in research infrastructure in the modern history of the UK. The facility, which started operating in January 2007, is one of only 22 3rd generation synchrotron facilities worldwide and enables researchers to conduct novel scientific experiments that are likely to shift the knowledge frontier in a number of scientific disciplines.[1]

While our analysis provides evidence on the impact of the establishment of Diamond on research and innovation, we are primarily interested in the geographical aspects of knowledge creation and diffusion. That is, we investigate whether the location choice of the Diamond Light Source has impacted on the geographical distribution of research in relevant scientific fields. The fundamental research question that we address in this way is whether the establishment of basic scientific research infrastructure, that is inherently indivisible, leads to a geographical clustering of related research in proximity to the infrastructure or whether the benefits of such scientific facilities spread across the country independently of its location. This, so far under-researched, question is particularly relevant with regard to 'lumpy', long-term, large-scale infrastructure investments such as a synchrotron. The analysis, therefore, also sheds light on the formation of research clusters and the implications for the geographical distribution of innovation.

In general, answering this question and establishing a causal effect of location choice on some outcome variable of interest is difficult due to the endogeneity inherent in location choice. However, in the case of the Diamond Light Source, we are able to address this problem by exploiting the availability of a 'control' location against which we can compare the 'treated' location. Diamond was built at the Harwell Science and Innovation Campus at the Rutherford Appleton Laboratory in Didcot in Oxfordshire. But there had previously been concrete plans to locate Diamond about 215 kilometers away in another research hub in Daresbury near Manchester. The final decision to locate Diamond in Oxfordshire was preceded by a heated and highly controversial political debate on the siting. Hence, by comparing the change in scientific research conducted in proximity to the location where Diamond was constructed and the 'runner-up' location (conditional on time-invariant unobservable as well as time-varying observable location-specific characteristics), we avoid confounding spatial effects caused by the

[1] There are a number of other 3rd generation synchrotron facilities in Europe including the European Synchrotron Radiation Facility (ESRF) in Grenoble, Soleil in Paris, and more recently ALBA, in Cerdanyola del Vallès, Spain. See http://www.lightsources.org

establishment of Diamond with those caused by unobserved, time-varying, location-specific characteristics.[2]

Our main focus is on tracing the geographical distribution of relevant research using scientific publications. We provide some additional evidence of the impact on patents to assess potentially broader effects on innovation. These two codified forms of knowledge are particularly suitable measures of research output and innovation in the context of our analysis given the nature of the scientific research enabled by Diamond. First, research conducted at the facility can be regarded as 'cutting edge', which makes it likely to result in findings publishable in scientific academic journals and capable of meeting the 'new-to-the-world' threshold for patentability. Second, research at Diamond focuses on highly codifiable scientific disciplines such as structural biology, physics, chemistry, materials science, and engineering which makes it likely to result in patentable subject matter.

Our findings suggest that the establishment of Diamond in Didcot resulted in strong clustering of related research near to the facility. We find a statistically significant and economically important increase in academic publications with our main set of results indicating an increase in our measure of scientific output of about 6 standard deviations within a 25km radius of Diamond. This effect applies to research that is generated from experiments carried out directly at Diamond as well as related research that does not use the synchrotron facility. Our identification startegy allows us to interpret this as evidence in favor of local externalities, that is, research output in proximity to Diamond increased more following Diamond's opening than it would have had the synchrotron been located elsewhere. Our results show that this strong, positive effect does not extend beyond the direct proximity to Diamond. We demonstrate that this result is robust to a number of variations of our empirical specification as well as changes in the construction of our measures of research input and output.

Our results contribute to the literature on the importance of agglomeration externalities produced by indivisible scientific research facilities for science and innovation. This literature focuses overwhelmingly on externalities between companies (Jaffe et al., 1993; Audretsch and Feldman, 1996a) or from university to private industry (Jaffe, 1989; Kantor and Whalley, 2009; 2012). We offer for the first time empirical evidence on the importance of local externalities created by basic scientific research infrastructure in forming clusters of scientific research.

This paper is organized as follows. Section 2 provides detailed information on Diamond and its location choice. Section 3 outlines the empirical approach taken to identify the impact of the establishment of Diamond. Section 4 describes the data used

[2]Since Diamond was placed in an existing cluster, the challenge is in separating any possible cluster-related externalities from the (local) externalities created by Diamond.

in the analysis while Section 5 discusses the results. Section 6 presents a number of robustness checks and Section 7 concludes.

2 Diamond Light Source

2.1 UK's 3rd generation synchrotron

The Diamond Light Source is a synchrotron facility. Synchrotron facilities are circular particle accelerators that produce beams of x-rays, infrared and ultraviolet light (see Figure 1).[3] Such synchrotron light is useful to study small objects, such as molecules and atoms, whose visualization requires light with shorter wavelengths than available in microscopes.[4] Diamond consists of a 561 meter storage ring and has a total floor area of 45,500 m^2.

Diamond is funded by the UK Science and Technology Facilities Council (86%) and the Wellcome Trust (14%). After the siting decision had been taken in March 2000, the two-phase construction of Diamond was initiated in early 2003. In Phase I, the buildings for the synchrotron facility were constructed and the first seven beamlines established. The cost of Phase I is GBP 263 million. User operations on the beam lines constructed in Phase I began in January 2007. In Phase II, another 15 beamlines are currently being added to the facility, requiring another GBP 120 million in investment. The different beamlines are optimized for specific research applications. There are currently 19 operational beamlines at Diamond which are used to conduct experiments in various fields including condensed matter physics, materials science, biology and medicine serving both basic and applied research. This provides ample scope for the creation of new publishable as well as patentable knowledge in a range of applied scientific fields.

Diamond superseded the existing synchrotron in the UK which was located at the STFC Daresbury Laboratory near Manchester. The Synchrotron Radiation Source (SRS), which opened in 1981, was the second synchrotron light source in the UK. It replaced the UK's first synchrotron NINA built in 1964 also in Daresbury (NINA was closed in 1977). Given Diamond's technical superiority, the SRS became obsolete and was closed in August 2008. The main difference between SRS – a 2nd genera-

[3] A synchrotron consists of a large ring-shaped tube into which charged particles are fired from a linear accelerator and in which they are accelerated further. The ring is enclosed by magnets that keep the particles in the tube 'on orbit'. The accelerated particles are ejected into a so-called storage ring in which they circulate without accelerating further. The continuous movement of the electrons, which is created by so-called insertion devices, results in electromagnetic waves, so-called synchrotron radiation. This radiation is captured in beamlines in which the radiation is used for experiments.

[4] There are three types of experiments that can be conducted at Diamond: (a) X-ray diffraction and scattering, (b) spectroscopy, (c) imaging and microscopy. Each of these techniques is more suitable for specific experiments.

tion synchrotron – and Diamond – a 3rd generation synchrotron – is how synchrotron light is generated. While 2nd generation synchrotrons rely on dipole bending magnets to produce synchrotron radiation, 3rd generation synchrotrons rely on so-called undulators/wigglers which cause electrons to wiggle producing more intense, brighter synchrotron light. This allows higher resolution and improves the synchrotron's applicability for x-ray microscopy to spectromicroscopy which benefits particular scientific fields such as crystallography. This suggests that Diamond and the SRS are not complementary but rather that Diamond's capabilities far outperform the SRS.[5]

Beamtime is granted after submission of a proposal which also specifies the amount of time the research team would like to use the facility and the beamline that will be used.[6] Beamtime is allocated to academic users through a scientific peer review panel and a panel that assesses technical feasibility.[7] Beamtime is free for academic users and corporate users that commit to putting the research results into the public domain. Private companies wanting to maintain the ownership of any intellectual property resulting from their work at Diamond may apply for beamtime, but are liable to a usage fee.[8]

To facilitate access for researchers, Diamond offers onsite accommodation for its users. It also provides funding for travel and subsistence for UK academics. Alternatively, researchers also have the possibility to use Diamond remotely – users can send their samples to Diamond where the experiments are then conducted by Diamond staff which entails some restrictions on the flexibility with which experiments can be conducted.

2.2 Location choice

Our identification strategy rests on a strong controversy that arose in the siting of Diamond. Initially, the government had firm plans to site the new synchrotron at the STFC Daresbury Laboratory next to the existing UK synchrotron. However, the Wellcome Trust suggested that the new synchrotron should be built instead at the Harwell

[5] Our conversations with scientists that conduct experiments at Diamond confirmed its technical advantage over the SRS. Scientists regard Diamond as crucial for their research and report that before its existence, they either would have used similar synchrotron facilities abroad, for example in France of Switzerland, or they would not have been able to pursue their specific line of research.

[6] There are three non-proprietary access routes: (a) direct access, where prospective users submit proposals for individual projects that can last for a maximum of 6 months; (b) long term access, which provides access for projects for up to 2 years; and (c) block allocation, which allows to pool beamtime across different groups.

[7] The members of the academic peer review panel come from a wide range of UK and European universities, research institutions, and private companies. The list of panel members is available on Diamond's website: http://www.diamond.ac.uk/Home/ForUsers/academics/panel.html

[8] 80% of beamtime is allocated to external, i.e., academic and industrial, users. Industrial users can use only up to 10% of the beamtime for external users.

Science and Innovation Campus in Didcot (Oxfordshire) effectively co-locating Diamond with the Rutherford Appleton Laboratory (RAL). According to a range of news articles, Wellcome believed that "*greater scientific benefits would result from a location close to the existing neutron source* [ISIS] *and to Medical Research Council units and the University of Oxford*" (*Nature*, 2 December 1999).[9] Hence, the main argument was to concentrate research facilities in a single location (Didcot was already home to ISIS, one of the leading pulsed neutron and muon sources worldwide) to strengthen national centers of excellence in research. Supporters of the Daresbury location, in contrast, argued that given the expected applicability of Diamond to only a limited number of scientific disciplines, Wellcome was overstating the importance of geographical proximity to the so-called Oxford-London-Cambridge Golden Triangle. Instead, they argued that relocation of staff from the existing synchrotron at Daresbury to Didcot would represent a substantial but unnecessary expense and deprive the Manchester region of publicly funded top scientists employed at the SRS.[10] The controversy received broad public attention and led to heated debates in Parliament as well as to discussions in a large number of news channels and newspapers including reports by the BBC, Financial Times, the Times Higher Education, The Guardian, as well as scientific media, such as *Nature*. The issue received particular public interest as supporters of the Daresbury site framed the controversy within the longstanding debate on the North-South divide in terms of scientific research infrastructure in the UK.

In March 2000, the government announced that the synchrotron would be built at the Rutherford Appleton Laboratory near Oxford. However, the debate continued and even more than a decade later, Diamond's website still justifies this decision by stating that "*[t]he Harwell Science and Innovation Campus is a thriving hub of scientific research and there is a high concentration of users within the region. Diamond is surrounded by a number of scientific research facilities making the site a centre of excellence in terms of tools and expertise and therefore the ideal location for the UK's new synchrotron.*" This statement implies that geographical proximity to potential users is the main argument in favor of the decision to locate the facility in Didcot near Oxford. The underlying assumption is that geographical proximity influences not only a potential user's decision to employ the facility to conduct research but also the impact of the resulting scientific output. However, the strongly controversial debate surrounding the decision to locate Diamond near Oxford and the arguments offered by both sides suggest that *ex ante* both locations were similarly competitive clusters

[9]It is unclear whether the Wellcome trust was first to favor Didcot over Daresbury or whether the UK Office of Science and Technology pronounced its preference for Oxfordshire first (see a Parliamentary debate in March 2000).

[10]Savings were reported to be at the order of GBP 32 million (*Nature*, 16 September 1999).

from a scientific point of view with respect to research that could be conducted using a synchrotron. This provides the basis for our identification strategy outlined in the following section.

3 Empirical Strategy

3.1 Theoretical Framework

To provide some intuition for the basic mechanisms at work in our set-up, we start with a simple conceptual framework. We assume that there is a fixed number of geographical areas $a = 1, ..., N$ in which scientists work in relevant scientific fields. Researchers in area a produce scientific output p_{at} in period t. Output is produced with two inputs, (i) research infrastructure S_{at}, as well as (ii) total available research output (i.e. publications) denoted by R_{at}. We assume that the overall, available research output is a function of total research output excluding the knowledge created in a,[11] $R_{at} = g\Big(\sum_{a \neq b} \delta_{ab} p_{bt}\Big)$ where δ_{ab} is a constant that reflects the geographical proximity between areas a and b (e.g. inverse geographic distance). The fact that research infrastructure S_{at} is area-specific captures the notion that access to a research facility is easier the closer the facility is located to a researcher. This assumption still allows for an infrastructure shock to affect several areas. In addition, the production function includes a productivity shifter A_{at} specific to area a in period t which combines a range of factors such as area-specific technology shocks which affect the productivity of the two inputs equally. With these assumptions in hand, we can write a simple production function as

$$p_{at} = f(A_{at}, S_{at}, R_{at}) \tag{1}$$

where p_{at} is increasing in both inputs. This simple framework allows us to illustrate the two main effects at work – a direct and an indirect effect – of an increase in S_{at} as a consequence of Diamond (Appendix A.1 shows how we derive this expression):

$$\frac{\partial p_{at}}{\partial S_{at}} = \underbrace{\frac{\partial f(A_{at}, S_{at}, R_{at})}{\partial S_{at}}}_{\text{Direct Effect}} \times \underbrace{\left[1 - \left(\frac{\partial f(A_{at}, S_{at}, R_{at})}{\partial R_{at}} \times \Omega\right)\right]^{-1}}_{\text{Indirect Effect}} \tag{2}$$

where $\Omega = \frac{\partial g(\cdot)}{\partial p_{at}} \Big[\sum_{a \neq b} \big(\frac{\partial g(\cdot)}{\partial p_{bt}} \frac{\partial f(\cdot)}{\partial R_{bt}} \big) \Big]$.

[11]Including p_{at} would produce a trivial feedback effect since we assume for simplicity that these effects are contemporaneous.

In our set-up, a positive infrastructure shock, i.e. an increase in S_{at}, has a positive direct effect on research output ($\frac{\partial f(A_{at},S_{at},R_{at})}{\partial S_{at}} > 0$) because it enables researchers to conduct novel experiments that push the knowledge frontier. Hence, even in the absence of externalities, the shock creates more output through this direct effect. In the presence of externalities, however, the shock creates output above and beyond the direct effect. Here, externalities emerge because the output of researchers in area a depends on the aggregate research output. In this way, the infrastructure shock in a directly increases output of researchers in area a (*direct* effect) and feeds back into the production of output via the total research output, i.e., a's output affects b's output which in turn affects a's output via R_{at} (*indirect* effect). The indirect effect introduces a nonlinearity into the production function which produces localized externalities. The effect is localized because R_{at} is increasing in δ_{ab}, that is, the indirect effect increases in geographical proximity between areas a and b. Hence, the indirect effect acts as positive multiplier in Equation (2) as long as $0 < \frac{\partial f(\cdot)}{\partial R_{at}} \times \Omega < 1$. Obviously, this set-up is simplistic in many ways (e.g. it does not explain the optimal choice of inputs), and it should not suggest that local externalities only emerge because of the use of other researchers' output as research input. A range of factors can produce local externalities. Still, the framework illustrates one possible way in which geographical proximity to infrastructure affects output directly but also indirectly through its effect on total research output. The following section explains how we empirically separate these two effects and test for their presence.

3.2 Empirical Approach

We want to know if the establishment of the Diamond Light Source in Didcot resulted in the geographical concentration of research and innovative output in proximity to its location beyond what would have happened, had Diamond been sited elsewhere. We focus on the geographical distribution of research within the UK because, as observed by a member of Parliament in a debate on the siting of Diamond "*[w]hether one flies from Tokyo to Daresbury or from Tokyo to Oxford is irrelevant.*" (Hon. Stunell, March 2000).[12] The object of interest is the geographical distribution of research activity conducted in scientific fields related to Diamond. Our main focus will be on explaining differences in research activity across different geographical areas in the UK where we define geographical areas as Local Authorities (LAs).[13] We rely on observable mea-

[12]It might nevertheless be interesting to investigate potential international spillovers. For example, British universities and researchers in geographical proximity to Diamond might have found it easier to initiate international collaborations due to the need by foreign researchers to team up with local researchers to have better and more flexible access to the synchrotron facility.

[13]We face a trade-off in the choice of spatial units for our analysis. Activity is sufficiently 'rare' that we want to aggregate up to avoid problems of excess zeros, but we want to use small spatial scales to

sures of research for our analysis: academic journal publication, author, and affiliation counts. We also provide some evidence on the impact on patents although journal articles are our central focus mainly because of the substantially longer time lag between the research being conducted and a corresponding patent application becoming visible to the public (as discussed in the Data Section 4). In addition, establishing a link with the research relevant to Diamond is substantially more difficult for patents than scientific articles (see Section 4). This focus also means that we are not directly concerned with potential 'byproducts' created by the establishment of a basic research facility (David et al., 1992), such as the formation of related scientific networks. However, these 'byproducts' are certainly among the factors that could be driving the outcome measures used in our analysis. To help with exposition, in this section we will refer to (academic) paper counts for Local Authority areas (the main focus of our empirical results). All methods extend readily to alternative counts and different units of observation.

Empirically, the main challenge in establishing a causal link from Diamond to the geographical distribution of related scientific research is the potential endogeneity of Diamond's location (which corresponds to A_{at} in Section 3.1 above). If (correctly anticipated) changes in the geographical distribution of knowledge determined the location of Diamond, then we may incorrectly attribute those changes to a causal impact of Diamond. This affects the identification of the direct effect of Diamond as well as potential externalities created by the synchrotron. As discussed above, our main strategy for dealing with this endogeneity is to exploit the availability of a 'runner-up' location: Daresbury.[14] This section provides details.

Our starting point is the following estimating equation:

$$p_{at} = \alpha + \sum_t D_t + \sum_r D^r_{DI} + \sum_r D^r_{DI} \times I(t \geq 2007) + \epsilon_{at} \qquad (3)$$

better capture any changes to the geographical distribution of activity. Experimentation with larger (Travel to Work Areas) and smaller (postcode areas) units suggest that Local Authorities represent the most appropriate observational unit for balancing this trade-off.

[14]In contrast to Greenstone et al. (2010) or Malmendier et al. (2012), who rely on several winners and runner-ups for comparison, we only have a single winner and a single runner-up. However, for identification, we rely on differences in variation in scientific output before and after the opening of Diamond by scientists located across the UK as a function of their geographical distance to both locations. As such, our analysis is related to a broader literature that uses variation across treated and control locations to estimate causal effects on endogenous location choices. For example, Redding and Sturm (2008) examine the costs of remoteness using the quasi-random variation arising from the division of Germany after World War II. Ahlfeldt et al. (2012) use both the division and reunification of Berlin to generate exogenous variation in market access at the city-block level to distinguish agglomeration forces from other location-specific unobserved factors such as shared amenities or common natural advantages. Similarly, Draca et al. (2011) estimate the causal effect of policing on crime using quasi-random variation generated by the response to the 2005 terrorist attacks in London (as a response central London received additional policing relative to other London boroughs).

where p_{at} is the count of published academic papers from authors employed in area a at time t; D_t a dummy variable taking value one if year is equal to t, zero otherwise; D^r_{DI} are a set of R 'ring' dummies which take value one if the area is within a given distance of *Diamond*, zero otherwise;[15] $I(t \geq 2007)$ is a 'post-Diamond' indicator variable taking value one from 2007 onwards (the year Diamond opened for external users), zero otherwise; ϵ_{at} is an idiosyncratic error.

In our main analysis we use three ring dummies corresponding to distances 0-25km, 25km-125km, 125km-175km.[16] The ring dummies allow for the fact that research activity may not be uniformly distributed in areas close to Diamond even before the facility is operational. In our main analysis the comparison group comprises areas located more than 175km from Diamond (the omitted category).[17] In this specification, the interaction of these ring dummies with an indicator for years after the opening of Diamond is intended to capture any impact of Diamond on research activities in areas close to the facility. The time dummies allow for the fact that aggregate research activity may vary over time.

As usual, anything that causes the error ϵ_{at} to be correlated with the distance to Diamond (as captured by the ring dummies) will bias coefficients on the distance dummies and hence our estimate of the impact of Diamond. The main source of such correlation, in our context, arises because the decision where to locate Diamond was influenced by an assessment of the research potential of different places. To help address this problem, we can control for observable characteristics of locations as follows:

$$p_{at} = \alpha + \sum_t D_t + \sum_r D^r_{DI} + \sum_r D^r_{DI} \times I(t \geq 2007) + \\ + \beta_1 X_{at} + \beta_2 X_{at} \times I(t \geq 2007) + \epsilon_{at} \quad (4)$$

where X_{at} are characteristics of areas that may affect research activity. Equation 4 provides consistent estimates of the treatment effect of Diamond if $Cov(\epsilon_{at}, D^r_{DI} | X_{at}, X_{at} \times I(t \geq 2007)) = 0 \; \forall r$. The inclusion of X_{at} controls for the fact that observable area characteristics may drive both the number of papers published and the location of Diamond, introducing correlation between ϵ_{at} and D^r_{DI} in Equation 3.

The interaction term $X_{at} \times I(t \geq 2007)$ further allows for the possibility that the impact of these area characteristics on research activity may change at the same time as Diamond was opened in a way that was correctly anticipated by government when

[15]We use straight line, rather than travel distances, because these are much easier to calculate and very likely to be highly correlated with actual travel distances. See Combes and Lafourcade (2005).

[16]The specification of the distances implies that Oxford is included in the first distance ring, Cambridge and London in the second, and the third ring includes cities such as Nottingham or Cardiff.

[17]We verify the robustness of our results for different distance ring definitions in Section 6.2.

making its decision about the location of Diamond. This may seem unlikely, but research funding decisions provide a crucial mechanism through which such effects could occur (and where the government may be able to correctly 'anticipate' decisions it will make in the future). Research funding in the UK is allocated both through independent research councils and through the Higher Education Funding Council (HEFCE). HEFCE funding is based on a HEFCE run research assessment exercise (RAE) which last reported in 2008 and HEFCE rules on how to use the RAE to allocate funds. If government knew, for example, that more research funding would be concentrated on centres of excellence following the RAE exercise then it would anticipate increased funding (and hence academic articles and patenting) for areas near Didcot, regardless of the location of Diamond. If this influenced the decision to locate Diamond in Didcot, then we need to control for the interaction term in Equation 4. In practice, the arguments in favour of including the interaction term are weakened by the fact that the decision on where to locate Diamond was taken in 2000, meaning that government would need to be correctly anticipating RAE outcomes in 2008 and funding decisions fairly far in advance. The arguments for including X_{at} are somewhat stronger – characteristics that affect research activity clearly influence the decision on Diamond and do not change that quickly over time. That said, if the location of Diamond causes changes in X_{at} then controlling for it will lead us to *underestimate* the impact of Diamond.[18]

In Equation 4 we may still worry that characteristics unobservable to the econometrician affect both research activity and the location of Diamond. If these characteristics are time invariant, then we can use the panel dimension of the data to control for them by estimating:

$$\begin{aligned} p_{at} = \alpha_a + \sum_t D_t + \sum_r D^r_{DI} \times I(t \geq 2007) + \\ + \beta_1 X_{at} + \beta_2 X_{at} \times I(t \geq 2007) + \epsilon_{at} \end{aligned} \quad (5)$$

where α_a is now a fixed effect for area a and everything else is as in Equation 4 (note that the terms in $\sum_r D^r_{DI}$ drop out as the distance ring dummies are time-invariant). This still leaves the possibility that something unobservable, but time varying affects both research activity and the location of Diamond. One concrete concern may be the tendency for existing 'clusters' of innovation to strengthen over time.[19] Given that we know Diamond was sited in an existing research cluster, this will overestimate the impact of Diamond if this clustering effect is observed in the research areas most closely associated with Diamond (in ways that are not fully captured by observable

[18] Angrist and Pischke (2009) refer to this as the 'bad control' problem.

[19] See, for example, Audretsch and Feldman (1996b) and Feldman and Francis (2004).

characteristics X_{at}). We see this as the main identification problem for estimates of the causal effect of Diamond based on Equation 5. To address this concern we use the availability of a runner up location at Daresbury. As discussed above, Daresbury also represents an existing cluster of activity in this area. So if any positive effect of Diamond is driven purely by the tendency for existing clusters to strengthen over time then we should observe a similar pattern of increased activity in areas close to the centre of the alternative cluster in Daresbury. This suggests that we estimate:

$$p_{at} = \alpha_a + \sum_t D_t + \sum_r D^r_{DI} \times I(t \geq 2007) + \\ + \sum_r D^r_{DA} \times I(t \geq 2007) + \\ + \beta_1 X_{at} + \beta_2 X_a t \times I(t \geq 2007) + \epsilon_{at} \quad (6)$$

where D^r_{DA} are a set of R 'ring' dummies which take value one if the area is within a given distance of *Daresbury*, zero otherwise and everything else is as before.[20] If the synchrotron at Daresbury had continued to operate, then comparing the coefficients on D^r_{DA} and D^r_{DI} would give us the impact of Diamond controlling for any average tendency for innovation to concentrate around existing geographical clusters. These estimates would be consistent provided that $Cov(\epsilon_{at}, D^r_{DI}|X_{at}, X_{at} \times I(t \geq 2007), \alpha_a) = 0$. Exploiting the availability of the control location, our identifying assumption is that conditional on a range of location-specific characteristics as well as location fixed effects, changes in the geographic distributions of research activity in related scientific disciplines would have been the same around Didcot and Daresbury in the absence of the construction of Diamond. Section 5.1 is careful to provide descriptive evidence in support of this identifying assumption.

By estimating Equation 6 we use a difference-in-difference specification to test whether the geographical distribution of research changes after the opening of Diamond. In our context, two factors complicate the interpretation of the resulting parameter estimates. The first complicating factor arises because, strictly speaking, Equation 6 only provides estimates of the treatment effect of Diamond if there are no spillovers between the treatment and control groups which are due to treatment (i.e. the opening of Diamond). In our context, spillovers can arise for various reasons, including global externalities (research advances), interactions (increased collaboration across UK universities), and general equilibrium effects (increase in the supply of researchers in the

[20] We correct for overlaps in the Diamond and Daresbury distance rings by allocating a given location to either the Diamond or the Daresbury distance ring depending on whether it is closer to Diamond or Daresbury.

relevant fields). To the extent that these spillovers raise research activity across the UK we will underestimate the impact of Diamond on the *level* of research activity taking place in proximity to Diamond but we still correctly capture the effect on the geographical *distribution* of activity. If, however, any positive spillover effects are particularly pronounced for the two strongest clusters of activity (at Didcot and Daresbury) then we underestimate both the impact on levels *and* the geographic distribution of activity.

A second complicating factor, works in the opposite direction. As we made clear above, the 2nd generation synchrotron at Daresbury was closed shortly after the opening of Diamond, so comparing the coefficients on D^r_{DA} and D^r_{DI} gives us the total effect of these two changes. In other words we might conflate the treatment effect of opening Diamond and the 'distreatment' effect of closing Daresbury.[21] Assuming that these effects are opposite in sign, then estimating Equation 6 will cause us to overestimate the treatment effect of Diamond. In practice this may not be a major problem because Diamond, as a 3rd generation Synchrotron, allowed for far more advanced research than the existing 2nd generation synchrotron at Daresbury. This implies that the location of the synchrotron did not simply move from Daresbury to Didcot, but a new type of facility was opened in Didcot that enabled researchers to conduct novel types of experiments which rendered the existing synchrotron technologically obsolete. Nevertheless, to test for this issue, we can use the existence of a third cluster of activity in Newcastle-upon-Tyne, based at the Institute for Cell and Molecular Biosciences.[22] Using the same logic as before, this suggests that we estimate:

$$\begin{aligned} p_{at} = \alpha_a + \sum_t D_t + \sum_r D^r_{DI} \times I(t \geq 2007) + \\ + \sum_r D^r_{DA} \times I(t \geq 2007) + \sum_r D^r_{NT} \times I(t \geq 2007) + \\ + \beta_1 X_{at} + \beta_2 X_{at} \times I(t \geq 2007) + \epsilon_{at} \end{aligned} \tag{7}$$

where D^r_{NT} are a set of R 'ring' dummies which take value one if the area is within a given distance of *Newcastle-upon-Tyne*, zero otherwise and everything else is as before. Comparing the coefficients on D^r_{DI} to D^r_{NT} give us the treatment effect of Diamond, while comparing the coefficients on D^r_{DA} to D^r_{NT} give us the (dis)treatment effect of closing Daresbury. This identification relies on the assumption that strengthened 'clustering' has the same effect across the three largest clusters of activity in the UK. We can check whether this is true for the third largest cluster by comparing our estimates from

[21] We are grateful to Gabriel Ahfeldt for drawing our attention to this point.

[22] Our choice of the Institute for Cell and Molecular Biosciences is explained by the *observed* clustering of relevant research around the Institute/Newcastle-upon-Tyne.

the diff-in-diff-in-diff specification (Equation 7) to the total effect estimated from the diff-in-diff specification that does not use the existence of a third cluster (Equation 6). For these reasons, Equations 6 and 7 are our preferred specifications. We do, however, supplement our analysis with a number of variations of our main model specifications, discussed in Section 6.

While specifications 6 and 7 account for the endogeneity inherent in Diamond's chosen location, the ring dummies do not distinguish between Diamond's direct and indirect effects discussed above. The framework presented in Section 3.1 suggests a straightforward way to separate these two effects. As we discuss in detail in the Data Section 4, we have data on research output that resulted directly from work at Diamond as well as from related research (where scientists did not rely on Diamond for their research). Defining p_{at} as a combination of both types of research output allows us to obtain an estimate of the combined effects of Diamond. However, if we limit p_{at} to related research, the coefficients on the ring dummies measure only the indirect effect because this research output was not generated by using the synchrotron directly. Hence, we can obtain estimates of both the direct and indirect effects within the empirical framework described above depending on how we define p_{at}. The following section describes in more detail how we identify direct and related research output resulting from Diamond.

4 Data

The main challenge with regard to data collection consists in identifying relevant research input and output and its location. As explained above, we focus on scientific publications, but provide additional evidence based on patent data.

Our starting point is a complete list of scientific publications that has resulted from work at Diamond. All users of the Diamond synchrotron are registered and report any scientific publication that results from the beamtime that they have been allocated. The list contains 347 publications (as of December 2010) in 121 scientific journals. We refer to this set of publications as 'Diamond Articles'.

For these articles we collect the corresponding information on authors and their affiliations. We find that the 1,760 researchers listed as authors in these publications are affiliated to 441 institutions within the UK and abroad.[23] Since author names and affiliations are not consistently reported in the same manner across the different journals, we standardized the data (as described in the appendix). Since we focus in

[23]Different departments at the same university are counted as different affiliations. For example the Department of Chemistry at the University of Oxford is regarded as a separate affiliation from the Department of Physics at the University of Oxford.

our analysis on publications by UK based researchers, we drop all articles that do not have at least one author with a UK affiliation. This reduces the number of articles to 332 with 1,282 UK-based authors affiliated to 194 different UK institutions. This set of articles, author names and affiliations represents the core set of information used in our analysis (see Section 5.1). In order to determine the geographical location of researchers within the UK, we identify the postcodes of all affiliations in the UK and match the data with Code-Point data which contains National Grid co-ordinates.[24]

In a second step, we use the complete set of 347 Diamond Articles to retrieve similar scientific publications.[25] Similarity is defined by the overlap in cited references.[26] We pick the five most similar articles for each of our Diamond Articles,[27] yielding a total of 1,528 articles.[28] We also collect related articles imposing the additional restriction that articles have to be published in either a field journal that pertains to the same field as the original article (e.g. 'Crystal Growth & Design' and 'Acta Crystallographica' which are both crystallography field journals) or a general interest journal (e.g. 'Science'). However, imposing this journal-based restriction on the selection of related articles effectively means that articles are on average less similar to our Diamond articles in terms of their reference overlap. This means that we use this restricted set of similar articles only to test the robustness of our results (see Section 6.3). We then proceed as with the Diamond Articles, that is we standardize author names and affiliations. We keep only authors that have at least one affiliation in the UK. The postcode of a UK affiliation is matched with the Code-Point data to map the author's location. Appendix A.3 contains a more detailed description of how we retrieved similar academic publications. We refer to the set of publications identified in this way as 'Related Articles'.

In a third step, we collect patent data. The patent data come from the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT) version April 2012.[29] We conduct the analysis with patents filed at the EPO and those published

[24]Code-Point data is provided by Ed*i*na Digimap. The Code-Point data provides a precise geographical location for each postcode unit in the UK determined by its National Grid co-ordinates given by Easting and Northing values and therefore allows an accurate determination of distances between two objects in the UK. Given the grid points for object i and object j, distances are calculated as $Distance = \sqrt{\mid northing_i - northing_j \mid^2 + \mid easting_i - easting_j \mid^2}$.

[25]Since we are interested in finding any scientific articles related to research conducted at Diamond, we do not restrict the set to only articles by UK-based authors.

[26]ISI Web of Knowledge (www.isiknowledge.com) offers a search tool to identify such articles.

[27]We also experimented with alternative ways of retrieving related articles, for example based on keywords and abstracts. However, substantial differences across journals (e.g. only 54 out of the 121 journals report keywords), make these alternative procedures less suitable and they would require a greater amount of subjective assessment than our chosen method.

[28]Some articles are among the top five of several Diamond articles, which explains why this number is less than $347 \times 5 = 1,735$.

[29]The EPO releases new versions of PATSTAT twice a year, in April and October.

directly by the UK Intellectual Property Office (UKIPO) that have at least one UK-based inventor.[30] Patent data are only visible after a patent has been published. Hence, although we use the application date of a patent in our analysis, our sample of patents is limited to patents that have been published. Given the usual 18-month delay between application and publication date, this implies that we only have patent data at best until October 2010. In fact, we see a considerable drop in the number of filings already towards the end of 2009 which is attributable to this reporting delay and motivates us to only use patent filings up to 2008 in our analysis. This limitation of the available patent data is our main motivation for relying principally on academic publications in our analysis. Another limitation is that in contrast to the official list of academic publications from Diamond, we do not have any official list of patents that are the direct outcome of research conducted at Diamond. This means we have to retrieve relevant patents by searching for patent documents that list 'Diamond researchers' as inventors.[31] Hence, we first match the set of 1,760 author names to inventor names that appear on any patent in the set that we have extracted from PATSTAT.[32] Appendix A.4 contains a description of the matching process. We find 191 authors to be inventors of a total of 779 patents. This represents the set of patents created by researchers working at Diamond. However, in contrast to academic articles published by Diamond users, for patents applied for *after* the opening of Diamond we cannot reliably determine whether the patent has resulted directly from research at Diamond.

To retrieve similar patents, as a next step, we exploit patents' IPC codes to retrieve patents protecting similar technologies.[33] More specifically, we search for patents with a similar, narrowly defined IPC profile as the patents identified through the 'Diamond author' names (see Appendix A.5). The IPC similarity search algorithm yields a total of 6,713 patents that protect technologies for which Diamond is potentially relevant. We then use postal addresses of the 9,080 inventors listed on these patents to geographically 'locate' the corresponding inventive activity. We thus extract postcodes from inventors' addresses to identify their geographical location by matching them with Code-point data.[34] Finally, we standardize inventor names and create a unique inventor identifier to

[30]Hence, the set of patents includes patents that were (a) filed directly with the UKIPO, (b) filed with the EPO, and (c) published by the UKIPO or EPO although received through the Patent Cooperation Treaty (PCT) channel that list at list one inventor with a UK address. In case (c), the application was originally made with the World Intellectual Property Organization (WIPO), but the examination is still conducted by the national patent office or the EPO (in case of so-called Euro-PCTs) which publishes and grants the patent.

[31]'Diamond researchers' are any authors that are listed on any of the 347 scientific publications resulting directly from Diamond.

[32]We limit the search for patents applied for after 1980.

[33]The International Patent Classification (IPC) is a hierarchical classification allocating patents into technology areas.

[34]In order to extract postcodes from inventors' addresses, we first corrected misspelled or missing

avoid counting the same inventor name spelled in different ways as multiple inventors.[35]

5 Results

In this section, we consider results when using academic articles, their authors, and the corresponding research institutions as our measure of research activity. We first offer some descriptive evidence and then discuss the main analytical results. The main results are based on Local Authorities as the geographical unit of observation and use counts of academic articles as our measure for research output. Results for patents are reported in section 6.1. Results for alternative specifications and output measures are reported in the robustness section 6.2.

5.1 Descriptives

As discussed in Section 4, we have information on an initial set of 347 Diamond Articles - published academic articles that result directly from experiments conducted at Diamond. The quality of the academic journals in which these Diamond Articles are published is relatively high, but varies substantially. Using the simple impact factor as a measure for journal quality, the average impact factor is a high 5.5 with a lower but still relatively high median of 3.5. The minimum and maximum are 0.4 (Acta Crystallographica Section E) and 49.9 (Acta Crystallographica Section A) respectively.

There are a total of 1,760 authors for these Diamond Articles. There are, on average, five authors per article with a minimum of 1 and a maximum of 24. These authors are affiliated with 441 institutions worldwide. On average, there are 4.2 affiliations per article. Slightly more than half (56%) of all affiliations are outside of the UK with most foreign authors affiliated with institutions in the US, Germany, and France. There are 1,282 authors with at least one UK affiliation. For reasons discussed in Section 3 - although we use the full set of Diamond Articles to identify related publications - we focus only on authors with British affiliations when considering the impact on the geographical distribution of research.[36] This means dropping 15 articles which have no British affiliated authors to leave us with a sample of 332 Diamond Articles with 1,282 authors affiliated to 194 British institutions.

Table 1 shows some descriptive statistics for these 332 Diamond Articles. There

postcodes in inventors' addresses and then retrieved them by searching the inventor address field in PATSTAT for any UK postcode that is contained in a register of postcodes that we created. To make this approach feasible, this was done at the 'postcode district' level, i.e., using the up-to four characters before the space (e.g., OX2 of OX2 6UD).

[35]PATSTAT offers such an id variable, but it is often incorrect. To address this, we created an algorithm that groups the same inventor names that have been spelled or input differently.

[36]This means we also exclude Northern Irish affiliations.

are, on average, 5.7 authors per article. Co-authors tend to share affiliations, so that there are markedly less institutional affiliations per article - the mean is 2.2 for this sample. The median number of institutional affiliates per author is 1, although some authors have more than one (either because they have multiple affiliations or because they change institution at some point in the sample). The table also shows data on the geographic distribution of researchers listed on Diamond Articles in terms of distances (in km) to Diamond and Daresbury before and after the establishment of Diamond. These data suggest that, on average, authors are located considerably closer to Diamond in the years before 2007 (and the establishment of Diamond). After 2007 the distance to both Diamond and Daresbury is smaller than pre-2007 although the difference appears to be a lot stronger for Diamond: the average distance from Diamond is 180km pre-2007, 155km for 2007 on, whereas the average distance from Daresbury is only 10km less for 2007 on (changing from 206km to 196km). This provides some preliminary evidence that researchers that eventually published articles based on work done at Diamond were located closer to Diamond than Daresbury before the opening of Diamond and were located even closer after it became operational. This, however, may simply reflect the fact that the location of Diamond was in some sense 'optimal' with respect to likely users which is why our regression analysis accounts for the endogeneity of location choice.

The lower panel of Table 1 shows some descriptive statistics for the set of Related Articles. On average, there are 3.8 authors per article, with the co-authoring decision again favoring same institution, so that the number of affiliations per article is lower at 1.7. When we look at the geographic distribution of these authors, we see that the mean and median distances are both very close to that of 'Diamond Authors.' We see a similar pattern in terms of authors being located in closer geographical proximity to Diamond after its opening in 2007 (on average 6km). Average distances to Diamond are in fact slightly smaller before the opening of Diamond than in the case of Diamond authors.

Maps 2 and 3 visualize the distribution of authors of Diamond and related articles across the UK before and after Diamond became operational. The maps plot the number of authors (as many times as they appear on separate publications) in a given location (as determined by the postcode of the authors' affiliation) summed over two periods: before the opening of Diamond 2003-2006 and after the opening of Diamond 2007-2010. The maps also show the locations of Diamond and Daresbury as well as the corresponding distance rings.[37] We see some research activity both around Daresbury

[37]The Diamond and Daresbury distance rings overlap in maps 2 and 3. We eliminate any such overlap in our regression analysis. For example, if the location of a given research output falls into both the 125km distance rings of Diamond and Daresbury, we assign the location to either Diamond's

and Diamond's eventual location in the period before Diamond opened its beamlines. A comparison with the map that plots the data for 2007-2010 shows clear evidence for increased activity both around Daresbury and Diamond, although the level of activity appears to have increased considerably more around Diamond than Daresbury. The increased clustering of research activity around Diamond appears to occur in direct proximity to Diamond within the 25km distance band.

Figure 4 offers additional preliminary evidence for clustering around Diamond post-opening. The figure shows the number of academic articles – only Related Articles – by authors located within 25km distance of either Diamond (solid line) or Daresbury (dashed dark grey line) along with the total number of academic articles (dot-dashed light grey line). The figure highlights two striking features of the data: first, pre-Diamond, there is little relevant academic research output especially in direct proximity to Diamond and Daresbury, which supports our view that Diamond enabled researchers to break new ground.[38] Second, the number of academic articles published by researchers close to Diamond increases signficantly shortly after Diamond was opened, whereas the line remains essentially flat around Daresbury. This evidence strongly suggests a highly localized (25km) clustering effect around Diamond. Because Figure 4 uses only data for related publications, the plot provides strong, descriptive evidence for local externalities created by Diamond.

To explore this further, Figure 5 shows annual coefficient estimates (β_{Ct}) from the regressions $p_{at} = \alpha_a + \sum_t D_t + \beta_{Ct} D_C^{25} \times D_t + \epsilon_{at}$ (with $C = [DI, DA]$) for Diamond and Daresbury (within 25km) where $t = 2000, 2001, ..., 2010$, and 2007 (the year of Diamond's opening) is the omitted category. These regressions pick up any pre-Diamond effects and therefore provide direct evidence on our identifying assumption of comparable pre-Diamond trends in both locations. In fact, the figures confirm the similarly low pre-Diamond trends around Diamond as well as Daresbury. Whereas there is only a very moderate reaction in terms of publications after 2007 in the Daresbury area, the figure for Diamond shows the significant increase in academic activity within 25km of Diamond. The remainder of this section makes these comparisons more precise by providing estimates for the specifications developed in Equations (3) to (7).

5.2 Regression results

We start by providing estimation results for Equations (3) to (5) in Table 3. The dependent variable is the LA-by-year count of scientific articles (Table 2 contains the corresponding descriptive statistics). We begin with the combined set of Diamond and

or Daresbury's 125km distance ring depending on whether its distance to Diamond is smaller or equal to its distance to Daresbury.

[38]Although this may partly reflect the way we construct related articles as discussed in Section 4.

related articles which means estimates reflect the combined direct and indirect effects of Diamond. Later we estimate separate models for a sample of only related articles. Column [I] reports OLS results when we simply include time dummies and three ring dummies corresponding to distances 0-25km, 25km-125km, 125km-175km (with the omitted category more than 175km). Consistent with our earlier descriptive statistics, these dummies capture the geographical clustering of research within 25km of Diamond. Results in column [II] show what happens when we interact these ring dummies with a 'post-Diamond dummy' - an indicator for years after the opening of Diamond. In this specification, the interaction of these ring dummies with the post-diamond dummy captures the impact of Diamond on research activities in areas close to the facility. As is clear from column [II] the coefficient on the interaction term for the 0-25km ring is large and statistically significant (at the 10% level).

As discussed above, one possible explanation of these results is that locations differ in terms of their research potential and that this research potential may explain both the location of Diamond and any differences in research activity. The remaining specifications in Table 3 deal with this possibility. Column [III] introduces measures of local skill composition (%NVQ4 and above) and size to capture differences in LA research potential, while Column [IV] interacts these characteristics with the post-Diamond dummy (Equation 4) to allow the effect of research potential to change at the same time as Diamond is up and running. Neither of these changes make much difference to the overall results although it is interesting to note that we find in Column [IV] a small negative post-Diamond effect on research activity 125-175km away from Diamond. Columns [V] to [VII] allow for the possibility that time invariant unobservable factors may explain both the distribution of research activity and the location decision on Diamond by introducing LA fixed effects (on their own - column [V] and in combination with the research potential variables - columns [VI] and [VII] - see Equation 5). Again, results on the geographical clustering of post-Diamond publications within 0-25km are essentially unaffected.

Clearly, we cannot rule out the possibility that something unobserved and time varying drives these results (because it is the within-area variation in publication counts pre- and post-Diamond that we use to identify the effects of Diamond). As explained above, however, we can rule out one concrete concern that the post-Diamond effect is simply driven by the tendency for existing 'clusters' of innovation to strengthen over time (which we see as the main identification problem for estimates of the causal effect of Diamond based on Equation 5). To recap, we control for this possibility by using the availability of a runner up location at Daresbury. Results are reported in Table 4. Column [I] reports results when we include ring dummies for Daresbury interacted with the post-Diamond dummy. We see that the geographical clustering close to Diamond after 2007 is *not* replicated around Daresbury. Column [II] shows that this conclusion is robust to the introduction of observable time varying characteristics of locations that capture research potential. Column [III] introduces area fixed effects to control for unobservables, while Column [IV] introduces both area fixed effects and observable characteristics. Again, results are essentially unchanged. If the positive effect of Diamond is driven purely by the tendency for existing clusters to strengthen over time then we should observe a similar pattern of increased activity in areas close to the center of the alternative cluster in Daresbury - and these results suggest that we do not.

Recall, however, that Daresbury may be affected by a negative 'distreatment' effect that occurs from the shut-down of the second generation synchrotron that used to operate on that site. While there is reason to be somewhat sceptical of this possibility given the big differences between the 2nd and 3rd generation technologies, we address this issue by estimating Equation 7 which includes an additional set of 'Newcastle' ring dummies intended to capture any post-Diamond change in the geographical clustering of research around the Institute for Cell and Molecular Biosciences. Column [I] in Table 5 reports results (for the interacted terms) when including fixed effects and all three sets of dummies. The coefficients on the Newcastle dummies are positive, but not statistically significant at any reasonable level. Columns [II] and [III] show that these findings do not change when we consider pairwise comparisons by estimating equation (6) for Diamond and Newcastle or for Daresbury and Newcastle. Finally, Column [IV] shows that these results are robust to controlling for observable characteristics of locations that might affect research potential. These results mean that, even accounting for a general tendency of clusters (in fields relevant to Diamond) to strengthen over time, we find a strong positive effect of Diamond on research output in the area close to Diamond. At the same time, we find little evidence for either a distreatment effect or a strengthening of geographical clusters independent of the effect of Diamond.

So far, we used LA-level counts of academic articles as the outcome variable. This includes articles produced by researchers working directly at Diamond as well as related articles (see discussion above in Section 4). To obtain estimates of the indirect effect, Table 6 restricts the article count to related publications, that is, only publications that have not resulted from direct work at Diamond. The results shown in Table 6 indicate a positive effect of Diamond on 'related articles' within direct proximity (25km ring) of Diamond. In fact, the pattern of estimates is very similar to that for total article counts although the post-Diamond coefficients fall considerably in magnitude as a result of the trimmed article counts. Still, research output within a 25km radius of Diamond shows an increase in related articles of about 5 standard deviations, which is only slightly less than what we obtained when using the total number of articles. This suggests that

Diamond affects not only the location of research that relies on access to the facility directly, but also that of related research and hence provides strong evidence for the presence of local externalities created by Diamond.

To investigate the drivers of the observed clustering around Diamond following the establishment of the 3rd generation synchrotron, we vary our baseline model in two ways. First, in Table 7 we show results when we ignore the number of publications by author and instead use as our dependent variable author counts by LA and year (i.e. we count authors only once independently of their number of publications in a given year). We view this as a measure of research input rather than output, which allows us to ask whether the clustering effect is created by an increase in the number of scientists in proximity to Diamond. In addition, we also use information on the ordering of authors in a given publication. In the sciences, by convention the position of an author in the list of authors is a strong indicator of the author's role in the research that has led to the publication.[39] This means by taking into consideration the ordering of authors in a given publication, we are able to weigh author counts by authors' relative importance for a given research output. Table 7 shows that we find a strong, positive, and statistically significant effect on the number of researchers within the 25km Diamond distance ring whereas no such effect can be seen around Daresbury. Diamond affects the *number* of people publishing not just the amount of papers published. This conclusion holds even when we take into account the importance of the contribution of a given author to published articles. Second, Table 8 shows results when using the number of institutions by LA and year as our dependent variable (i.e. we count institutions within LAs that appear as an affiliation at least in one article published in a given year). This can be regarded as an alternative measure of research input and allows us to ask whether relevant research is conducted at a larger number of institutions within proximity of the clusters. The corresponding estimates are positive within a 25km radius of Diamond but statistically indistinguishable from zero. This implies that the clustering effect appears to be driven by an increase in the number of scientists working on related research rather than an increase in the number of institutions where relevant research is conducted in proximity to Diamond.

Table 7 suggests that the increase in the number of publications in direct proximity of Diamond is driven by an increase in the number of scientists. This begs the question whether this increase is at least partly driven by researchers that move closer to

[39] The first and last author are usually perceived to have contributed the most to an article whereas authors appearing in the middle receive less credit (for survey evidence on this perception see Wren et al., 2007). This means that we assign the first and last authors the same score whereas the score drops the further down an author name appears in the byline.

Diamond when the synchrotron facility became operational. We identify moving scientists through changes in the affiliations that they indicate on their publications. We are only interested in scientists that moved between geographically distinct institutions after Diamond was opened.[40] Figure 6 shows the change in distances to Diamond and Daresbury for moving scientists. The numbers denote individual scientists.[41] If a given scientist is located above the 45°-degree line, he moved closer to Diamond/Daresbury after Diamond opened. The right-hand-side scatterplot suggests that scientists moved on average further away from Daresbury (the average distance before Diamond's opening was 179km and after its opening 211km). The pattern is less conclusive for Diamond in the left-hand scatterplot. While 16 scientists moved closer to Diamond, 12 scientists moved away. Yet, the average distance decreased from 168km to 134km. Nevertheless, only five scientists moved within a 25km radius of Diamond while at the same time five scientists moved out of the 25km radius. This analysis shows that only few scientists moved across geographically distinct locations after Diamond opened (1.3% of all scientists in our sample who account for 3.6% of publications). While scientists move on average closer to Diamond, few scientists move into direct proximity of Diamond. This implies that the strong clustering effect that we observe within the 25km distance ring is unlikely to be driven by the movement of scientists.[42] The lack of movement may be at least partly explained by the fact that (senior) academic positions are not easily changed, especially because locating in direct proximity to Diamond would most likely require a position either at Oxford University or the Rutherford Appleton Laboratory in Didcot, which are both very competitive workplaces.

Table 9 shows results when we restrict author and institution counts to authors and institutions that appear on related articles. The results in Columns [I] and [II] of Table 9 show that the coefficients on the 25km ring dummies around Diamond are no longer statistically significant, although still positive and large in magnitude. This means that there is no statistically significant increase in the number of authors post-Diamond when we disregard researchers that work directly at Diamond. This in combination with our findings in Table 6, that is, a statistically significant increase in the number of related publications within the first distance ring around Diamond, suggests that Diamond has not lead to an increase in the number of scientists working in relevant fields, but Diamond enabled these scientists in its geographical proximity to increase their relevant research output – even without working directly at Diamond. This provides additional evidence for the presence of externalities as a consequence of Diamond. It also allows

[40] Results are not affected if we also include researchers that moved shortly before Diamond opened.

[41] There are only 28 scientists that moved between geographically distinct institutions after Diamond opened.

[42] This makes it also unlikely that the effect is driven by researchers around Didcot that would have moved had the synchrotron been located elsewhere.

us to interpret the results of Table 7, which combined scientists that worked directly at Diamond and those that did not work at Diamond, as evidence that the increase in the total number of scientists is driven by scientists working directly at Diamond. Finally, the results in Columns [III] and [IV] of Table 9 confirm the results of Table 8 that the increase in research output is not driven by an increase in the number of institutions at which scientists work on related topics.

6 Robustness

In this section, we complement our analysis with a number of robustness exercises that vary the underlying data as well as our empirical specifications. First, we explore potential patterns when relying on patents instead of academic publication as our measure of research output. Second, we test a number of variations of our main specifications. Third, we use the alternative set of related articles where we impose the additional restriction that articles have to be published in either a field journal that pertains to the same field as the original article or a general interest journal (see Section 4).

6.1 Patents

As discussed in Section 4, we successfully matched 191 Diamond Authors to inventor names on patent documents. These 191 authors appear on 779 patents as inventors. For our regression analysis, we limit the data to patents applied for between 2000 and 2008. This reduces the number of patents filed by 'Diamond Inventors' to 556. The IPC similarity-based algorithm retrieves an additional 3,555 patents filed between 2000 and 2008 that list at least one UK-based inventor. Table 10 re-runs the specifications shown in Table 3 with the patent data. The results indicate a strong difference in the level of patenting around Diamond, which is robust to the inclusion of the post-Diamond distance ring interaction terms as well as covariates X_{at}. However, when we test for changes in patenting upon the opening of Diamond, overall we do not detect any statistically significant effect. When we control for location-specific time-invariant unobservables, the estimate in Column [V] of the coefficient on the 25km distance ring dummy is statistically significant – at 10%; but the effect vanishes when time-variant location characteristics are included (Column [VI]). Keeping in mind the two important limitations of the patent data discussed in Section 4, i.e., publication lag and the difficulty in identifying direct links with Diamond, we interpret these findings cautiously as suggesting that it may be too early to detect any 'Diamond effect' in patent filings. Nevertheless, the positive and statistically significant coefficient on the 25km Diamond distance ring suggests the existence of an innovative cluster in the area near Diamond independently of the siting of Diamond, which supports our efforts to account for the endogeneity of the location choice.

6.2 Variations of basic model

In this section, we explore the robustness of our main results to a number of modifications to our baseline specifications.

First, we use a different set of distance rings, changing the width of the rings as follows: the first ring is enlarged to 30km, the second shrinks to 100km and the third remains the same in width but now comprises the distance 100-150km. The omitted category are now locations beyond 150km. This increases the number of LAs included in the first ring around Daresbury from 8 to 13 LAs. The second distance band changes from 155 to 113 LAs in the case of Diamond and from 80 to 57 LAs in the case of Daresbury. The third distance ring now includes 69 (previously 41) LAs for Diamond and 23 (previously 7) LAs for Daresbury. The number of LAs included in the distance rings around Newcastle change from 5 to 7 for the first ring, from 17 to 10 for the second ring and from 9 to 11 LAs in the third ring. Table 11 shows the corresponding results for our main specifications. The table shows that our estimates on the first distance ring around Diamond are unaffected by the change in the width of the distance rings. Also the coefficients on the first distance rings around Daresbury and Newcastle remain statistically not significant. We also explore how our results change when we modify the number of distance rings. We use specifications that allow for either only two (25km and 125km) or four (25km, 75km, 125km, and 175km) distance rings. Table 12 shows that these modifications have little effect on our results. It is interesting to note, however, that allowing for a 25-75km distance ring points to a drop in relevant research output after the establishment of Diamond within that distance band.

Second, we look more directly for a 'Daresbury shutdown' effect. One way to do this is to test directly for the 'dis-treatment' effect by running Equation 5 only with Daresbury distance rings. A second possibility is to include an additional time dummy equal to one beginning in the year when Daresbury was closed (2008) and interacting this with the various distance rings. We have tried both with the corresponding results shown in Columns [I]-[III] of Table 13. The specification of Column [I] provides little, if any direct evidence for such a 'Daresbury shutdown' effect. However, results in Columns [II] and [III] indicate that such an effect may be partly at work. However, it is asking a lot of the data to separately identify two such offsetting effects (of Diamond opening and Daresbury shutting down) when they occur at almost the same time (2007 and 2008). Hence, the combination of the results shown in Tables 5 and 13 provide overall little evidence for a shutdown effect driving our estimates on the first distance ring around

Diamond. Table 13 also shows results when we test for a Diamond 'announcement effect' by including an indicator equal to one at the time when construction of Diamond began (2003).[43] There is some evidence of such an anticipation effect although our estimates on the first distance ring around Diamond remain largely unaffected by the inclusion of an 'announcement effect' dummy variable and its interaction with the distance rings.

Finally, Table 14 shows results when we limit the sample to LAs that report a positive author/article count in at least one sample year. This reduces the number of LAs from 379 to 76 and the sample size shrinks to 835 observations. The results remain qualitatively unchanged with the dummy variable for the first distance ring around Diamond being positive and now statistically significant at the 5% level.

6.3 Construction of related academic articles

Finally, we also modify the way we construct the set of related academic articles. As explained in Section 4, our main results are based on a set of similar articles where similarity is defined by the overlap in cited references with Diamond articles. To explore the sensitivity of our results to changes in the way we select related research, we also collect related articles restricting the set to articles to those that have been published in either a field journal that pertains to the same field as the Diamond article or a general interest journal. This restriction, however, means that the set of related articles will be on average less similar in terms of the reference overlap. Collecting related articles in this way produces a set of 539 related academic articles with 1,519 authors that are affiliated to 231 institutions. Table 15 shows the results. The estimates are very similar to those displayed in Tables 3 and 4, that is, the coefficients on the first Diamond ring dummy are positive and statistically significant whereas no such positive effect is observed around Daresbury.

7 Conclusion

Does the location of basic scientific research infrastructure affect its use and impact? This fundamental question is difficult to answer because the locations of scientific facilities are chosen in order to maximize their impact, posing a formidable challenge to empirical work that attempts to assess the causal relationship between location choice and impact. We address this question in the context of the Diamond Light Source, a 3rd generation synchrotron, in the UK and ask whether the location choice affected

[43] Our time series starts in 2000, the year the decision on the location of Diamond was taken. For this reason we rely on the date when the construction started rather than the announcement date.

where scientific research – that benefits from the existence of Diamond – is conducted. The existence of a 'runner-up' location (and a third geographical cluster) allows us to address the endogeneity inherent in the chosen location. Since the 'runner-up' location in Daresbury was home to the previous 2nd generation synchrotron, we also account for possible dis-treatment effects.

Overall, we find fairly strong evidence that Diamond caused the geographic concentration of relevant research close to Diamond (within a 25km radius) over and above what would have been expected had Diamond been located elsewhere. Our results show that this is because of both a direct effect (more scientists located close to Diamond use the facility) and local externalities created by the facility. We also find some (weak) evidence of a dis-treatment effect close to Daresbury when that facility closes. In summary, we find strong and robust evidence of a positive impact of Diamond on the geographical clustering of research output in form of scientific publications and input in form of scientists in close proximity to the newly opened facility.

Our findings point to several directions for potential future research. For example, it would be interesting to assess whether Diamond enabled scientists to conduct different and novel types of experiments in their field of research, which resulted in increased scientific output, or whether scientists switched fields to take advantage of the existence of Diamond. Borjas and Doran (2012) analyze the reaction of American mathematicians to the sudden influx of Soviet mathematicians following the collapse of the Soviet Union in terms of the research-field they choose to work in. Looking at Diamond would allow us to look at the effect of an infrastructure rather than a labor supply shock. Addressing this question, however, would involve collecting information on the whole research output of scientists over time. A related topic of interest is to track scientists that conducted experiments at the 2nd generation synchrotron in Daresbury to understand how they reacted to the opening of Diamond. It would also be interesting to explore whether Diamond induced new collaborations within the cluster around Didcot described in our results or with researchers outside of the cluster. Finally, while we attempted to assess the impact of Diamond on innovation through patent data, more work could be undertaken to investigate the effect of Diamond on innovation, especially in the private sector, to see whether it exhibits similar spatial clustering.

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A Appendix

A.1 Derivation of Equation (2)

We show how we obtain the expression in Equation (2) starting with the production function:

$$p_{at} = f(A_{at}, S_{at}, R_{at}) \tag{8}$$

The derivative of (8) with respect to infrastructure S_{at} is

$$\frac{\partial p_{at}}{\partial S_{at}} = \frac{\partial f(\cdot)}{\partial S_{at}} + \frac{\partial f(\cdot)}{\partial R_{at}} \frac{\partial R_{at}}{\partial g(\cdot)} \Big[\frac{\partial g(\cdot)}{\partial p_{bt}} \frac{\partial p_{bt}}{S_{at}} + ... + \frac{\partial g(\cdot)}{\partial p_{Nt}} \frac{\partial p_{Nt}}{\partial S_{at}} \Big] \tag{9}$$

since $\frac{\partial R_{at}}{\partial g(\cdot)} = 1$, we can re-write Equation (9) as

$$\frac{\partial p_{at}}{\partial S_{at}} = \frac{\partial f(\cdot)}{\partial S_{at}} + \frac{\partial f(\cdot)}{\partial R_{at}} \Big[\sum_{a \neq b} \frac{\partial g(\cdot)}{\partial p_{bt}} \frac{\partial p_{bt}}{\partial S_{at}} \Big] \tag{10}$$

using the fact that $\frac{\partial R_{bt}}{\partial g(\cdot)} = 1$, we can write

$$\frac{\partial p_{bt}}{\partial S_{at}} = \frac{\partial f(\cdot)}{\partial R_{bt}} \frac{\partial g(\cdot)}{\partial p_{at}} \frac{\partial p_{at}}{\partial S_{at}} \tag{11}$$

using (11) to re-write (10), we get

$$\frac{\partial p_{at}}{\partial S_{at}} = \frac{\partial f(\cdot)}{\partial S_{at}} + \frac{\partial f(\cdot)}{\partial R_{at}} \frac{\partial g(\cdot)}{\partial p_{at}} \frac{\partial p_{at}}{\partial S_{at}} \Big[\sum_{a \neq b} \frac{\partial g(\cdot)}{\partial p_{bt}} \frac{\partial f(\cdot)}{\partial R_{bt}} \Big] \tag{12}$$

re-arranging to isolate $\frac{\partial p_{at}}{\partial S_{at}}$ gives expression (2)

$$\frac{\partial p_{at}}{\partial S_{at}} = \frac{\partial f(\cdot)}{\partial S_{at}} \times \left[1 - \frac{\partial f(\cdot)}{\partial R_{at}} \frac{\partial g(\cdot)}{\partial p_{at}} \Big(\sum_{a \neq b} \frac{\partial g(\cdot)}{\partial p_{bt}} \frac{\partial f(\cdot)}{\partial R_{bt}} \Big) \right]^{-1} \tag{13}$$

A.2 'Diamond publications'

As of December 2010, there were 347 published scientific articles available on Diamond's website. These articles appeared in 121 scientific journals in various fields. While nearly all journals contain an abstract of the article, only 54 report keywords. These publications list a total of 1,760 authors. Author names had to be complemented and standardized as the way in which names are listed differs across journals. These authors are affiliated with 441 institutions all over the world. We also standardized the names of affiliations as the way in which they were reported differed in part considerably across journals. We also complemented addresses of affiliations whenever necessary by retrieving postal addresses from the relevant institutions' official websites.

A.3 Related academic publications

ISI Web of Knowledge offers a tool that searches for a given article the entire ISI Web of Knowledge database for other articles that contain the same references as the original article. We used this tool to retrieve all articles that share at least one reference with our 347 'Diamond articles'. We then computed a similarity score as the average of the number of shared references divided by the number of references in the 'Diamond article' and the number of shared references divided by the number of references in the article retrieved through ISI. We then retained for each of the 347 'Diamond articles' the five most similar articles, where similarity is measured by the similarity score based on the relative number of shared references. As an alternative, we also collected related articles imposing the additional restriction that articles have to be published in either a field journal that pertains to the same field as the original article (e.g. 'Crystal Growth & Design' and 'Acta Crystallographica' which are both crystallography field journals) or a general interest journal (e.g. 'Science'). In a next step, we recovered all author names and their affiliations from these similar articles. We standardized author names and affiliations and dropped all authors that report no affiliation with an entity in the UK. We then retrieved postcodes for all UK affiliations and matched them with Code-Point data to obtain the corresponding grid coordinates which allow us to compute distances to Diamond and Daresbury.

A.4 Matching author and inventor names

This appendix describes the algorithm used to match author names with inventor names. Both 'Diamond author' and inventor names were first standardized and then split into single words. For example, a 'Diamond author' or inventor called 'William A. Smith' is first transformed into 'william a smith' and then the name split into its three components 'william', 'a', and 'smith'. In a third step, all words are separately matched, that is 'william', 'a', and 'smith' are matched to for example 'anton', 'johan', 'smith'. Only inventor names that match at least two of the words of a 'Diamond author' name are retained. We applied a number of refinements to this matching algorithm in the actual matching process in order to avoid obvious false positives, such as for example in the case where names contain several initials, such as 'andrew c w smith' matching with 'michael w a c jefferson' only because both names have 'c' and ‘w’ in common. In a next step, we checked the data manually to eliminate false matches. Finally, we added authors’ affiliations and inventors’ addresses and check the data again manually. For example, we compared ‘william a smith’ (=‘Diamond author’) with ‘william smith’ (=inventor) and checked whether the author’s affiliation loosely coincides with the inventor’s address. Loosely means that if the affiliation is Oxford, we may accept an inventor’s address in Oxford (inventors often/usually indicate their home address). This, however, varies depending on the uniqueness of the name. So in case of ‘william smith’, this would not suffice as it is likely that there are several, different inventors’ called ‘william smith’ in the Oxford region which would make a false positive match very likely. If a person is for example called ‘henrietta krueger-hahn’, the same postcode/city is likely sufficient, however, to call it a definitive match given that it is unlikely that there is a second person with that same name that would be capable of applying for a patent. Hence, our matching algorithm involves both automated and some discretionary manual matching in order to minimize the occurrence of false positive or negative matches.[44]

A.5 IPC similarity algorithm

We retrieved patents that protect similar technologies as the ‘Diamond patents’ by creating an IPC similarity measure using the full IPC code as well as IPC groups.[45] Our algorithm that retrieves technologically similar patents works as follows: (1) drop all equivalents of the ‘Diamond patents’ from the set of potential matches because the overlap in IPCs would be perfect simply due to the fact that the equivalents protect the same underlying invention;[46] (2) match a ‘Diamond patent’s IPC profile (using both IPC symbols and groups) to the IPC profile of any patent in our set of UK/EPO patents held by UK residents; (3) compute the overlap for both types of patents, i.e., the number of matched IPCs divided by the total number of IPC of each type of patent – the ‘Diamond patent’ and the potential match – minus the number of matched IPCs. This corrects the score for the fact that patents with a larger number of IPCs are more likely to match with another patent’s IPC profile; (4) compute the matching score as the simple average of the two scores for matches at the IPC symbol- and group-level;

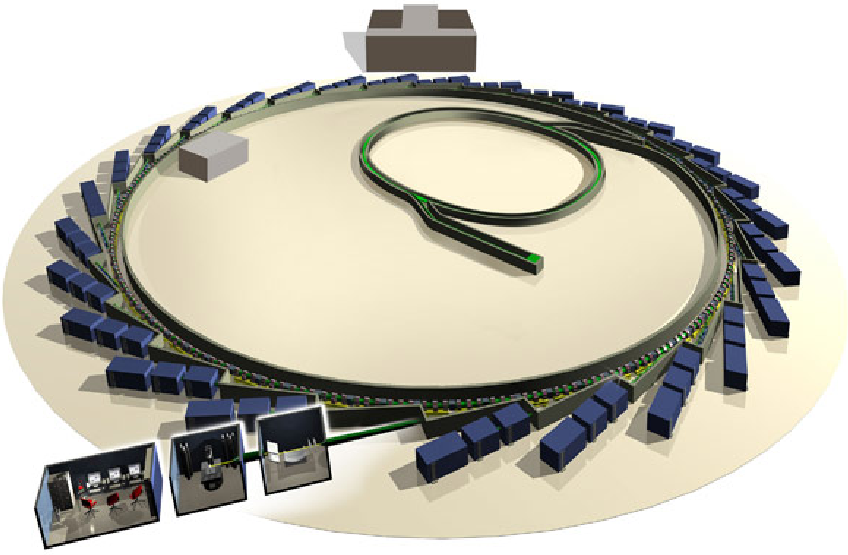
[44] For a more detailed discussion of the methodological challenges in the matching of patent data see Helmers et al. (2011).

[45] The importance of employing IPCs at the most detailed level possible is highlighted by the critique expressed by Fox-Kean and Thompson (2005) of the Jaffe et al. (1993) approach to constructing an IPC-based similarity measure. Jaffe et al. (1993) relied on IPC classes which Fox-Kean and Thompson (2005) showed to be technologically too heterogeneous to yield a meaningful similarity measure.

[46] Equivalents are defined as patents having the same set of priority documents. Note that our definition is inbetween EPO’s narrow DOCDB and broad INPADOC definition and corresponds to the first equivalents definition in Martinez (2010).

(5) keep only scores above the 99th percentile of the score distribution of all matched patents for each 'Diamond patent'. This means that we keep only the most similar patents although the similarity cut-off value therefore varies by 'Diamond patent' in absolute terms. This represents our set of patents protecting technologies relevant to Diamond.

Figure 1: Diamond synchrotron facility



Source: Diamond Light Source.

Figure 2: Academic publications: number of articles – **pre-**Diamond 2003-2006

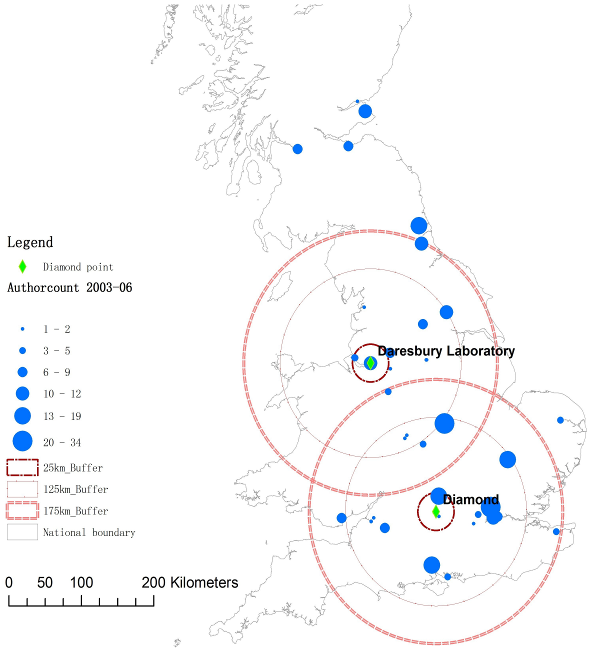


Figure 3: Academic publications: number of articles – **post-**Diamond 2007-2010

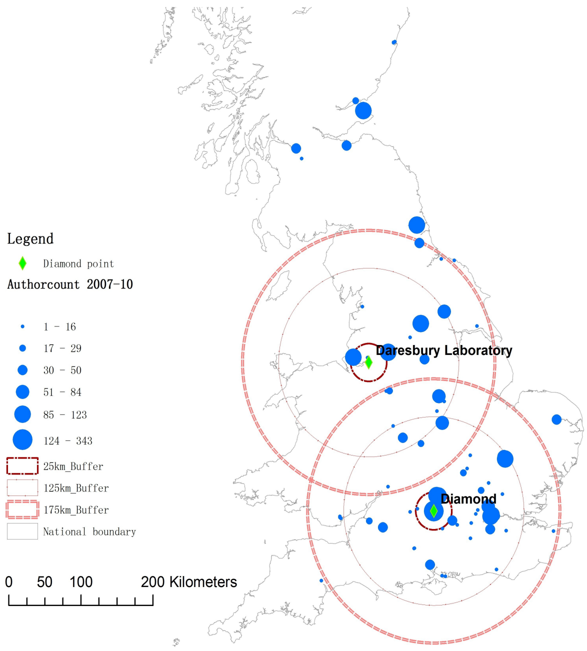


Figure 4: Academic publications: number of related articles – distance to Diamond and Daresbury (Before & After 2007)

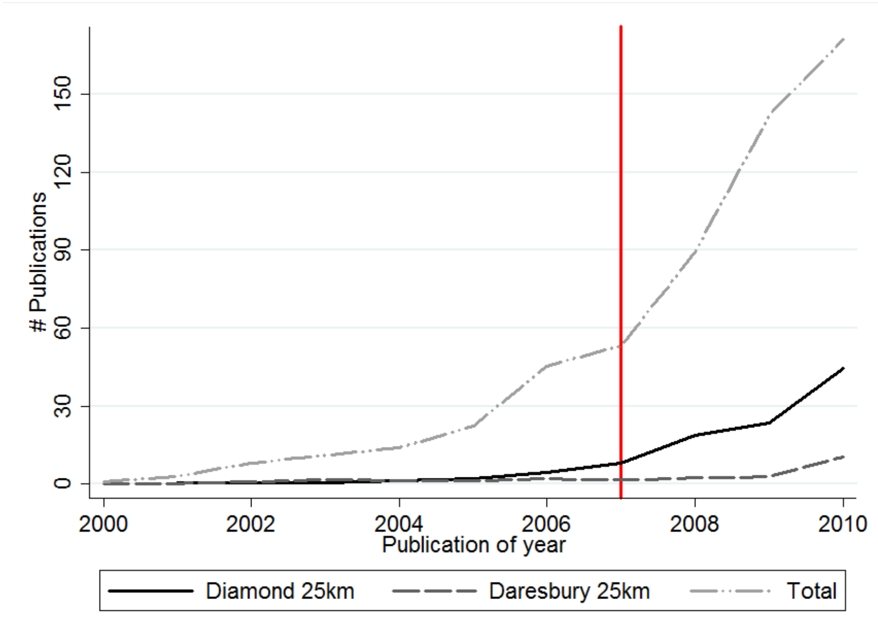
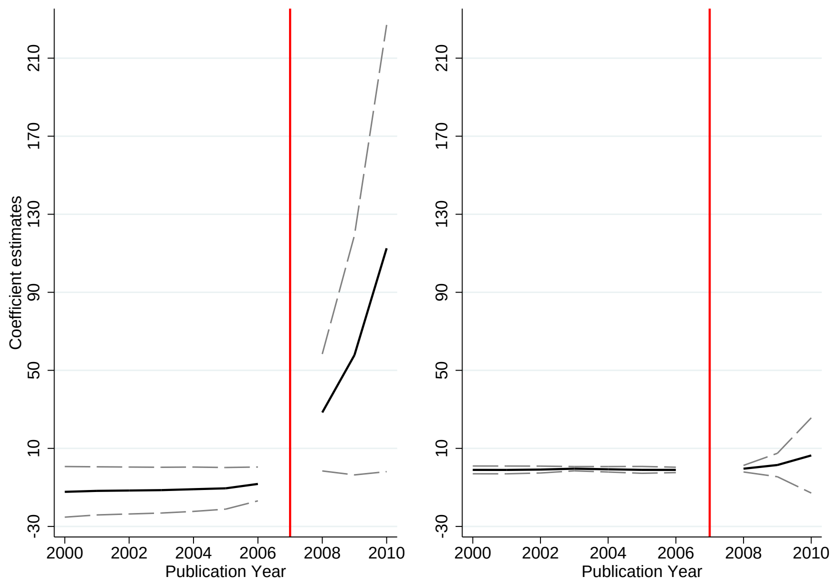
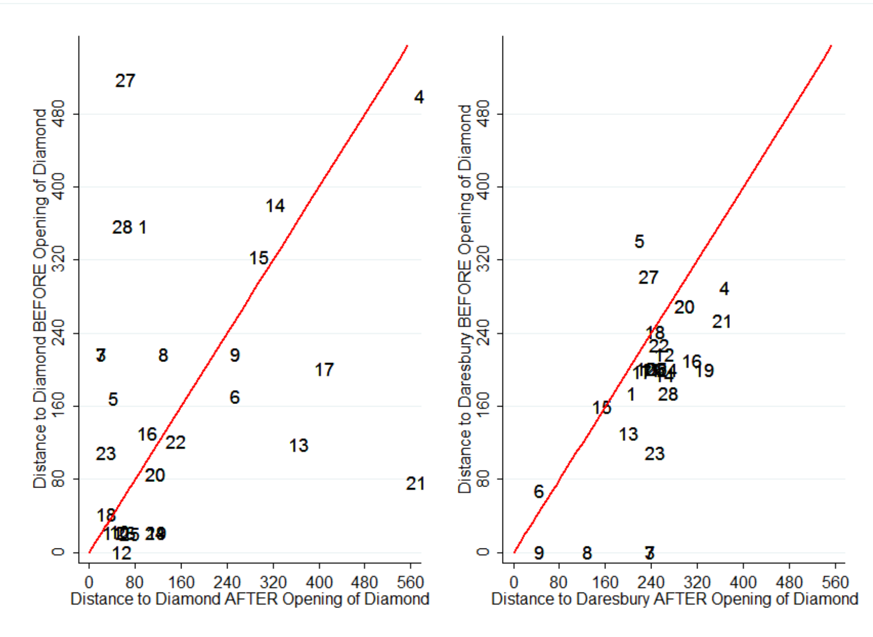


Figure 5: Academic publications: number of related articles – annual coefficient estimates for Diamond and Daresbury (Before & After 2007)



Notes: The two graphs show annual coefficient estimates β_{Ct} from the regressions $p_{at} = \alpha_a + \sum_t D_t + \beta_{Ct} D_C^{25} \times D_t + \epsilon_{at}$ (with $C = [DI, DA]$) for Diamond and Daresbury (within 25km) where $t = 2000, 2001, ..., 2010$, 2007 is the omitted category.

Figure 6: Moving scientists: Distance to Diamond and Daresbury (Before & After 2007)



Notes: The graphs show geographical distances to Diamond (left graph) and Daresbury (righ graph) before and after Diamond opened for the set of scientists (the numbers represent the individual scientists) that moved from one institution to another during that time period. Scientists above the 45°-line have moved closer to Diamond/Daresbury, whereas scientists below the 45°-line have moved further away from Diamond/Daresbury.

Table 1: Summary statistics for Academic publications

	Mean	Median	Std. Dev.	Min.	Max.
'Diamond' academic journal articles					
Descriptive Statistics of Authors & Affiliations (UK only)					
# authors per article	5.69	5	2.99	1	20
# affiliations per article	2.19	2	1.23	1	7
# affiliations per author	1.13	1	0.38	1	3
Geographical Distribution of 'Diamond' Authors' Affiliations					
$<$ 2007 (*Before* Establishment of Diamond)					
Distance (km) to Diamond	180.1	120.6	148.4	0	539.3
Distance (km) to Daresbury	206.2	219.4	76.7	0	340.0
$\geq$ 2007 (*After* Establishment of Diamond)					
Distance (km) to Diamond	154.8	117.3	152.1	0	623.4
Distance (km) to Daresbury	196.4	216.5	82.4	0	425.6
Related academic journal articles					
Descriptive Statistics of Authors & Affiliations (UK only)					
# authors per article	3.85	3	2.47	1	17
# affiliations per article	1.66	1	0.92	1	8
# affiliations per author	1.26	1	0.50	1	4
Geographical Distribution of Authors' Affiliations					
$<$ 2007 (*Before* Establishment of Diamond)					
Distance (km) to Diamond	170.5	120.6	136.9	0	554.3
Distance (km) to Daresbury	192.0	209.7	85.7	0	347.3
$\geq$ 2007 (*After* Establishment of Diamond)					
Distance (km) to Diamond	164.3	118.4	155.1	0	624.3
Distance (km) to Daresbury	199.2	212.1	84.6	0	426.7

Notes:
1) There are 332 academic articles, 1,282 'Diamond authors', that are affiliated to 194 institutions.
2) There are 520 related academic articles, 1,269 'related authors', that are affiliated to 223 institutions.

Table 2: Summary statistics for regression samples

	Mean	Median	Std. Dev.	Min.	Max.	Obs
Dependent variable						
# Authors	0.97	0	8.10	0	270	4,121
# Unique authors	0.74	0	5.51	0	159	4,121
# Unique authors weighted by position	0.37	0	2.72	0	79.58	4,121
# Articles (Diamond and Related)	0.31	0	2.39	0	84	4,121
# Articles (Related)	0.18	0	1.13	0	34	4,121
# Unique Institutions	0.15	0	0.84	0	20	4,121
# Patents (Diamond and Related)	1.97	1	4.44	0	55	3,364
Covariates						
# %NVQ4 and above	26.65	25.8	8.52	5.6	100	4,121
# Labor force	75.80	60.0	49.95	2.6	457.6	4,121

Table 3: **Academic Articles:** OLS (379 LA – 2000-2010)

		[I]	[II]	[III]	[IV]	[V]	[VI]	[VII]
Diamond	25km	6.204*	0.527*	0.171	0.491			
		(3.211)	(0.308)	(0.280)	(0.305)			
	125km	0.035	0.016	-0.148**	-0.001			
		(0.104)	(0.026)	(0.069)	(0.021)			
	175km	-0.218***	-0.031*	0.159***	-0.003			
		(0.067)	(0.018)	(0.058)	(0.017)			
Diamond × $I(t \geq 2007)$	25km		15.610*	15.627*	14.904*	15.604*	15.798*	15.009*
			(8.221)	(8.204)	(8.112)	(8.218)	(8.192)	(8.108)
	125km		0.053	0.024	-0.352**	0.050	-0.034	-0.377***
			(0.226)	(0.219)	(0.149)	(0.227)	(0.201)	(0.143)
	175km		-0.501***	-0.467***	-0.032	-0.505***	-0.388***	-0.102
			(0.145)	(0.141)	(0.125)	(0.146)	(0.110)	(0.120)
%NVQ4 and above				0.033***	0.003		0.032*	-0.001
				(0.012)	(0.002)		(0.018)	(0.012)
Labor force				0.007***	0.001***		0.094***	0.058***
				(0.001)	(0.000)		(0.016)	(0.015)
%NVQ4 and above × $I(t \geq 2007)$					0.069***			0.066***
					(0.022)			(0.022)
Labor force × $I(t \geq 2007)$					0.014***			0.009***
					(0.003)			(0.002)
Time dummies		YES	YES	YES	YES	YES	YES	YES
Fixed Effects		NO	NO	NO	NO	YES	YES	YES
R^2		0.106	0.212	0.244	0.278	0.211	0.062	0.095
Observations		4,121	4,121	4,121	4,121	4,121	4,121	4,121

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 4: **Academic Articles:** OLS (379 LA – 2000-2010)

		[I]	[II]	[III]	[IV]
Diamond	25km	0.529*	0.493		
		(0.309)	(0.305)		
	125km	0.018	0.002		
		(0.030)	(0.026)		
	175km	-0.028	-0.001		
		(0.023)	(0.020)		
Diamond × $I(t \geq 2007)$	25km	15.586*	14.919*	15.574*	15.048*
		(8.229)	(8.121)	(8.223)	(8.113)
	125km	0.028	-0.335	0.020	-0.334
		(0.286)	(0.217)	(0.290)	(0.214)
	175km	-0.526**	-0.015	-0.535**	-0.060
		(0.228)	(0.211)	(0.232)	(0.205)
Daresbury	25km	0.226	0.199		
		(0.201)	(0.213)		
	125km	-0.015	-0.016		
		(0.023)	(0.022)		
	175km	-0.005	0.014		
		(0.041)	(0.035)		
Daresbury × $I(t \geq 2007)$	25km	0.952	0.617	0.940	0.713
		(1.019)	(0.974)	(1.019)	(0.939)
	125km	-0.072	-0.030	-0.082	0.027
		(0.301)	(0.248)	(0.303)	(0.237)
	175km	-0.303	0.057	-0.310	0.017
		(0.314)	(0.247)	(0.319)	(0.244)
%NVQ4 and above			0.004		-0.001
			(0.002)		(0.013)
Labor force			0.001***		0.059***
			(0.000)		(0.015)
%NVQ4 and above × $I(t \geq 2007)$			0.070***		0.066***
			(0.023)		(0.022)
Labor force × $I(t \geq 2007)$			0.014***		0.009***
			(0.003)		(0.002)
Time dummies		YES	YES	YES	YES
Fixed Effects		NO	NO	YES	YES
R^2		0.214	0.278	0.214	0.095
Observations		4,121	4,121	4,121	4,121

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 5: **Academic Articles:** OLS (379 LA – 2000-2010)

		[I]	**[II]**	**[III]**	**[IV]**
Diamond × $I(t \geq 2007)$	25km	15.850*	15.726*		15.251*
		(8.224)	(8.221)		(8.114)
	125km	0.295	0.172		-0.121
		(0.229)	(0.223)		(0.162)
	175km	-0.260*	-0.383***		0.152
		(0.149)	(0.140)		(0.167)
Daresbury × $I(t \geq 2007)$	25km	1.216		0.822	0.949
		(1.003)		(1.016)	(0.928)
	125km	0.133		-0.259	0.211
		(0.241)		(0.291)	(0.188)
	175km	-0.328**		-0.721***	0.158
		(0.141)		(0.215)	(0.169)
Newcastle × $I(t \geq 2007)$	25km	1.792	1.669	1.399	1.547
		(1.909)	(1.908)	(1.915)	(1.716)
	125km	0.318	0.195	-0.074	0.445
		(0.434)	(0.431)	(0.464)	(0.320)
	175km	1.238	1.115	0.845	0.725
		(0.930)	(0.928)	(0.943)	(0.630)
%NVQ4 and above					-0.001
					(0.013)
Labor force					0.058***
					(0.015)
%NVQ4 and above × $I(t \geq 2007)$					0.068***
					(0.023)
Labor force × $I(t \geq 2007)$					0.009***
					(0.002)
Time dummies		YES	YES	YES	YES
Fixed Effects		YES	YES	YES	YES
R^2		0.219	0.216	0.040	0.096
Observations		4,121	4,121	4,121	4,121

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 6: **Academic Articles: Only Related Articles** OLS (379 LA – 2000-2010)

		[I]	**[II]**	**[III]**	**[IV]**
Diamond	25km	0.529*	0.493		
		(0.309)	(0.305)		
	125km	0.018	0.001		
		(0.030)	(0.026)		
	175km	-0.028	-0.001		
		(0.023)	(0.020)		
Diamond × $I(t \geq 2007)$	25km	5.968*	5.629*	5.960*	5.687*
		(3.404)	(3.320)	(3.401)	(3.309)
	125km	-0.018	-0.205*	-0.024	-0.208
		(0.160)	(0.122)	(0.162)	(0.121)
	175km	-0.311**	-0.049	-0.317**	-0.077
		(0.128)	(0.118)	(0.130)	(0.116)
Daresbury	25km	0.226	0.199		
		(0.201)	(0.213)		
	125km	-0.015	-0.016		
		(0.023)	(0.022)		
	175km	-0.005	0.014		
		(0.041)	(0.035)		
Daresbury × $I(t \geq 2007)$	25km	0.459	0.288	0.452	0.340
		(0.596)	(0.549)	(0.596)	(0.532)
	125km	-0.074	-0.052	-0.081	-0.021
		(0.162)	(0.137)	(0.164)	(0.131)
	175km	-0.196	-0.012	-0.200	-0.035
		(0.168)	(0.132)	(0.172)	(0.131)
%NVQ4 and above			0.003		-0.005
			(0.002)		(0.005)
Labor force			0.001***		0.034***
			(0.000)		(0.007)
%NVQ4 and above × $I(t \geq 2007)$			0.036***		0.035***
			(0.012)		(0.012)
Labor force × $I(t \geq 2007)$			0.007***		0.004***
			(0.001)		(0.001)
Time dummies		YES	YES	YES	YES
Fixed Effects		NO	NO	YES	YES
R^2		0.166	0.253	0.164	0.084
Observations		4,121	4,121	4,121	4,121

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 7: **Academic Articles – Channels: Inputs (unique author count)**
OLS (379 LA – 2000-2010)

		Unique author count			Weighted by byline position[ℜ]	
		[I]	**[II]**	**[III]**	**[IV]**	**[V]**
Diamond × $I(t \geq 2007)$	25km	33.685*	33.778*	34.378*	14.421*	14.734*
		(18.240)	(18.264)	(12.264)	(8.379)	(8.379)
	125km	-0.835**	-0.734	-0.108	-0.391	-0.065
		(0.367)	(0.551)	(0.398)	(0.285)	(0.209)
	175km	-0.193	-0.095	0.525	-0.038	0.286
		(0.300)	(0.515)	(0.416)	(0.267)	(0.219)
Daresbury × $I(t \geq 2007)$	25km		1.496	2.187	0.390	0.750
			(2.336)	(2.299)	(1.006)	(0.984)
	125km		0.118	0.723	0.099	0.410
			(0.610)	(0.484)	(0.320)	(0.258)
	175km		-0.117	0.553	-0.097	0.296
			(0.555)	(0.416)	(0.284)	(0.218)
Newcastle × $I(t \geq 2007)$	25km			3.429		1.664
				(3.756)		(1.831)
	125km			0.827		0.426
				(0.556)		(0.303)
	175km			2.614		1.401
				(2.069)		(1.113)
%NVQ4 and above		-0.014	-0.014	-0.014	-0.015	-0.015
		(0.029)	(0.029)	(0.029)	(0.014)	(0.014)
Labor force		0.182***	0.183***	0.183***	0.101***	0.101***
		(0.044)	(0.044)	(0.044)	(0.023)	(0.023)
%NVQ4 and above × $I(t \geq 2007)$		0.164***	0.165***	0.167***	0.089***	0.090***
		(0.060)	(0.061)	(0.061)	(0.032)	(0.032)
Labor force × $I(t \geq 2007)$		0.021***	0.020	0.019***	0.010***	0.009***
		(0.005)	(0.005)	(0.005)	(0.002)	(0.002)
Time dummies		YES	YES	YES	YES	YES
Fixed Effects		YES	YES	YES	YES	YES
R^2		0.082	0.082	0.082	0.074	0.074
Observations		4,121	4,121	4,121	4,121	4,121

Notes:
1) Dependent variable is unique author count by LA and year (each author counted only once independently of number of publications).
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.
5) [ℜ] Author counts weighted by the inverse average position in list of author names. First and last author assigned weight equal to one.

Table 8: **Academic Articles – Channels: Inputs (unique affiliation count)**
OLS (379 LA – 2000-2010)

		[I]	**[II]**	**[III]**	**[IV]**	**[V]**
Diamond × $I(t \geq 2007)$	25km	3.498	3.648	3.783	3.472	3.570
		(2.432)	(2.519)	(2.519)	(2.437)	(2.437)
	125km	-0.123*	-0.006	0.128	-0.150	-0.051
		(0.064)	(0.141)	(0.114)	(0.103)	(0.082)
	175km	-0.034	-0.272**	-0.138	-0.063	0.032
		(0.047)	(0.122)	(0.090)	(0.085)	(0.076)
Daresbury × $I(t \geq 2007)$	25km		0.037	0.172	-0.123	-0.014
			(0.219)	(0.202)	(0.188)	(0.173)
	125km		-0.072	0.059	-0.041	0.066
			(0.151)	(0.128)	(0.112)	(0.096)
	175km		-0.172	-0.180	-0.039	0.027
			(0.151)	(0.084)	(0.103)	(0.078)
Newcastle × $I(t \geq 2007)$	25km			0.434		0.243
				(0.558)		(0.461)
	125km			-0.014		0.033
				(0.130)		(0.089)
	175km			0.903		0.623
				(0.622)		(0.447)
%NVQ4 and above		-0.009***			-0.009***	-0.009***
		(0.003)			(0.003)	(0.003)
Labor force		0.034***			0.034***	0.035***
		(0.006)			(0.007)	(0.007)
%NVQ4 and above × $I(t \geq 2007)$		0.026***			0.026***	0.026***
		(0.008)			(0.008)	(0.008)
Labor force × $I(t \geq 2007)$		0.005***			0.005***	0.004***
		(0.001)			(0.001)	(0.001)
Time dummies		YES	YES	YES	YES	YES
Fixed Effects		YES	YES	YES	YES	YES
R^2		0.101	0.139	0.152	0.304	0.102
Observations		4,121	4,121	4,121	4,121	4,121

Notes:
1) Dependent variable is unique institutions count by LA and year (each institution counted only once independently of number of publications).
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 9: **Academic Articles – Channels: Inputs – Only Related Articles**
OLS (379 LA – 2000-2010)

		Unique author count		Unique affiliation count	
		[I]	**[II]**	**[III]**	**[IV]**
Diamond × $I(t \geq 2007)$	25km	7.521	7.709	2.591	2.671
		(5.012)	(5.012)	(1.981)	(1.980)
	125km	-0.271	-0.075	-0.158*	-0.076
		(0.166)	(0.117)	(0.083)	(0.062)
	175km	-0.097	0.097	-0.096	-0.017
		(0.157)	(0.125)	(0.067)	(0.059)
Daresbury × $I(t \geq 2007)$	25km	0.311	0.529	-0.081	0.009
		(0.724)	(0.714)	(0.157)	(0.145)
	125km	-0.020	0.177	0.060	0.027
		(0.177)	(0.137)	(0.086)	(0.071)
	175km	-0.125	0.115	-0.064	-0.006
		(0.160)	(0.116)	(0.078)	(0.057)
Newcastle × $I(t \geq 2007)$	25km		1.048		0.210
			(1.124)		(0.358)
	125km		0.143		0.013
			(0.137)		(0.068)
	175km		0.835		0.489
			(0.646)		(0.370)
%NVQ4 and above		-0.010	-0.009	-0.006***	-0.006**
		(0.007)	(0.007)	(0.002)	(0.002)
Labor force		0.053***	0.053***	0.022***	0.023***
		(0.011)	(0.011)	(0.003)	(0.004)
%NVQ4 and above × $I(t \geq 2007)$		0.046**	0.046***	0.018***	0.018***
		(0.017)	(0.017)	(0.006)	(0.006)
Labor force × $I(t \geq 2007)$		0.005	0.004***	0.003***	0.003***
		(0.001)	(0.001)	(0.001)	(0.001)
Time dummies		YES	YES	YES	YES
Fixed Effects		YES	YES	YES	YES
R^2		0.069	0.069	0.091	0.092
Observations		4,121	4,121	4,121	4,121

Notes:
1) In Columns [I] and [II], dependent variable is unique author count by LA and year (each author counted only once independently of number of publications). In Columns [III] and [IV], dependent variable is unique institutions count by LA and year (each institution counted only once independently of number of publications).
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 10: **Patents:** OLS (379 LA – 2000-2008)

		[I]	[II]	[III]	[IV]	[V]	[VI]
Diamond	25km	6.735**	7.226**	6.240*	6.140*		
		(3.347)	(3.614)	(3.481)	(3.456)		
	125km	1.460***	1.440***	0.988***	0.943**		
		(0.469)	(0.482)	(0.435)	(0.437)		
	175km	-0.469	-0.511	-0.067	-0.043		
		(0.347)	(0.356)	(0.286)	(0.287)		
Diamond × $I(t \geq 2007)$	25km		-2.211	-2.061	-1.717	-2.235*	-2.047
			(1.348)	(1.265)	(1.225)	(1.348)	(1.326)
	125km		0.085	0.001	0.194	0.079	0.204
			(0.184)	(0.197)	(0.238)	(0.181)	(0.200)
	175km		0.178	0.245	0.135	0.169	0.070
			(0.161)	(0.178)	(0.174)	(0.157)	(0.162)
%NVQ4 and above				0.090***	0.098***		-0.005
				(0.027)	(0.028)		(0.015)
Labor force				0.015***	0.015***		0.002
				(0.005)	(0.005)		(0.032)
%NVQ4 and above × $I(t \geq 2007)$					-0.032		-0.020*
					(0.016)		(0.011)
Labor force × $I(t \geq 2007)$					-0.002		-0.003
					(0.002)		(0.003)
Time dummies		YES	YES	YES	YES	YES	YES
Fixed Effects		NO	NO	NO	NO	YES	YES
R^2		0.051	0.052	0.104	0.105	0.000	0.000
Observations		3,364	3,364	3,364	3,364	3,364	3,364

Notes:
1) Dependent variable is patent count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.
5) Contains UK and EPO patent filings.
6) Patents allocated to years by application date.

Table 11: **Academic Articles – Robustness: Width of Distance Rings:**
OLS (379 LA – 2000-2010)

		[I]	**[II]**	**[III]**	**[IV]**	**[V]**
Diamond	30km	0.479				
		(0.305)				
	100km	-0.033				
		(0.028)				
	150km	0.039				
		(0.046)				
Diamond × $I(t \geq 2007)$	30km	14.854*	15.663*	14.994*	15.813*	15.089*
		(8.112)	(8.221)	(8.104)	(8.224)	(8.105)
	150km	-0.566**	0.083	-0.546**	0.233	-0.442*
		(0.245)	(0.235)	(0.248)	(0.213)	(0.232)
	150km	0.081	-0.065	0.103	0.085	0.206
		(0.335)	(0.361)	(0.332)	(0.347)	(0.333)
Daresbury	30km	0.108				
		(0.139)				
	100km	-0.022				
		(0.018)				
	150km	-0.005				
		(0.027)				
Daresbury × $I(t \geq 2007)$	30km	-0.099	0.413	0.082	0.563	0.216
		(0.673)	(0.671)	(0.642)	(0.664)	(0.638)
	100km	-0.012	0.007	0.051	0.157	0.167
		(0.225)	(0.309)	(0.211)	(0.293)	(0.202)
	150km	0.163	-0.052	0.197	-0.037	0.197
		(0.274)	(0.325)	(0.261)	(0.287)	(0.246)
Newcastle × $I(t \geq 2007)$	30km				1.798	1.236
					(1.443)	(1.287)
	100km				-0.312**	0.078
					(0.150)	(0.184)
	150km				0.738	0.414
					(0.722)	(0.471)
%NVQ4 and above		0.004		-0.003		-0.004
		(0.003)		(0.014)		(0.014)
Labor force		0.001		0.059***		0.059***
		(0.000)		(0.015)		(0.015)
%NVQ4 and above × $I(t \geq 2007)$		0.075***		0.079***		0.074***
		(0.026)		(0.026)		(0.027)
Labor force × $I(t \geq 2007)$		0.014***		0.009***		0.009***
		(0.003)		(0.002)		(0.003)
Time dummies		YES	YES	YES	YES	YES
Fixed Effects		NO	YES	YES	YES	YES
R^2		0.281	0.210	0.096	0.216	0.096
Observations		4,121	4,121	4,121	4,121	4,121

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 12: **Academic Articles – Robustness: # Distance Rings:**
OLS (379 LA – 2000-2010)

		[I]	[II]		[III]	[IV]
Diamond × $I(t \geq 2007)$	25km	15.063*	15.124*	25km	15.012*	15.215*
		(8.106)	(8.106)		(8.112)	(8.113)
	125km	-0.319**	-0.250*	75km	-0.692**	-0.482**
		(0.151)	(0.138)		(0.270)	(0.227)
				125km	-0.179	0.035
					(0.256)	(0.217)
				175km	-0.052	0.161
					(0.208)	(0.170)
Daresbury × $I(t \geq 2007)$	25km	0.728	0.810	25km	0.722	0.958
		(0.922)	(0.921)		(0.944)	(0.933)
	125km	0.042	0.079	75km	-0.143	0.078
		(0.170)	(0.154)		(0.250)	(0.212)
				125km	0.185	0.346
					(0.289)	(0.244)
				175km	0.027	0.166
					(0.246)	(0.172)
Newcastle × $I(t \geq 2007)$	25km		1.411	25km		1.564
			(1.710)			(1.716)
	125km		0.317	75km		0.435
			(0.303)			(0.354)
				125km		0.463
						(0.500)
				175km		0.725
						(0.629)
%NVQ4 and above		-0.001	-0.001		-0.003	-0.003
		(0.013)	(0.013)		(0.013)	(0.013)
Labor force		0.059***	0.058***		0.057***	0.057***
		(0.015)	(0.015)		(0.015)	(0.015)
%NVQ4 and above × $I(t \geq 2007)$		0.067***	0.067***		0.069***	0.071***
		(0.022)	(0.022)		(0.023)	(0.024)
Labor force × $I(t \geq 2007)$		0.009***	0.009***		0.009***	0.009***
		(0.002)	(0.002)		(0.002)	(0.002)
Time dummies		YES	YES		YES	YES
Fixed Effects		YES	YES		YES	YES
R^2		0.095	0.096		0.098	0.099
Observations		4,121	4,121		4,121	4,121

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 13: **Academic Articles – Robustness: Daresbury Shutdown and Diamond Construction Effects:** OLS (379 LA – 2000-2010)

		[I]	[II]	[III]	[IV]	[V]
			DARESBURY SHUTDOWN		DIAMOND CONSTRUCTION	
Diamond × $I(t \geq 2007)$	25km		15.251*	3.004	15.009*	14.877*
			(8.114)	(1.832)	(8.108)	(8.024)
	125km		-0.121	-0.242*	-0.377***	-0.136
			(0.162)	(0.146)	(0.143)	(0.156)
	175km		0.152	0.353*	-0.103	0.158
			(0.167)	(0.180)	(0.120)	(0.165)
Daresbury × $I(t \geq 2007)$	25km	0.789	0.949	0.249		0.899
		(0.944)	(0.928)	(0.604)		(0.901)
	125km	0.079	0.211	0.119		0.222
		(0.173)	(0.188)	(0.184)		(0.188)
	175km	0.085	0.158	0.414**		0.159
		(0.179)	(0.169)	(0.176)		(0.161)
Newcastle × $I(t \geq 2007)$	25km		1.547	0.310		1.530
			(1.716)	(0.387)		(1.686)
	125km		0.445	0.081		0.407
			(0.320)	(0.286)		(0.295)
	175km		0.725	-0.271		0.709
			(0.630)	(0.282)		(0.595)
Diamond × $I(Shut/Const)$	25km			16.346*		0.872***
				(8.841)		(0.301)
	125km			0.170		0.036
				(0.235)		(0.049)
	175km			-0.282		-0.015
				(0.178)		(0.044)
Daresbury × $I(Shut/Const)$	25km			0.919		0.119
				(1.302)		(0.163)
	125km			0.111		-0.024
				(0.271)		(0.050)
	175km			-0.356*		0.0001
				(0.181)		(0.049)
Newcastle × $I(Shut/Const)$	25km			1.634		0.040
				(1.853)		(0.097)
	125km			0.479		0.095
				(0.649)		(0.098)
	175km			1.323		0.039
				(0.992)		(0.143)
Daresbury Shutdown			-2.013***	-2.009***		
			(0.620)	(0.631)		
Diamond Construction					-1.751***	-2.029***
					(0.558)	(0.625)
Time dummies		YES	YES	YES	YES	YES
Fixed Effects		YES	YES	YES	YES	YES
R^2		0.042	0.096	0.109	0.095	0.098
Observations		4,121	4,121	4,121	4,121	4,121

Notes:
1) $I(Shut/Const)$ is either the $DaresburyShutdown$ or the $DiamondConstruction$ dummy variable depending on the specification.
2) Dependent variable is publication count by LA and year.
3) Controls: % NVQ4 and above; % NVQ4 and above × $I(t \geq 2007)$; Labor force; Labor force × $I(t \geq 2007)$.
4) Robust standard errors clustered at LA-level.
5) All regressions include a constant.
5) 379 instead of 380 LAs because no covariates available for Isles of Scilly.

Table 14: **Academic Articles – LAs with ≥ 1 author:**
OLS (76 LA – 2000-2010)

		[I]	[II]	[III]	[IV]
Diamond × $I(t \geq 2007)$	25km	18.793**	17.449*	17.482*	17.317*
		(9.061)	(9.059)	(9.176)	(9.069)
	125km	-0.924	-1.689***	-1.686	-1.836*
		(0.763)	(0.628)	(1.165)	(1.059)
	175km	-2.337	-2.825	-2.750**	-2.976***
		(0.539)	(0.744)	(1.043)	(1.055)
Daresbury × $I(t \geq 2007)$	25km			-1.000	0.369
				(1.946)	(2.173)
	125km			-1.045	-0.425
				(1.353)	(1.303)
	175km			-2.160	-0.127
				(1.463)	(1.431)
%NVQ4 and above		0.148*	0.026		0.026
		(0.078)	(0.067)		(0.067)
Labor force		0.066**	0.038		0.038
		(0.027)	(0.028)		(0.028)
%NVQ4 and above × $I(t \geq 2007)$			0.158**		0.157*
			(0.064)		(0.068)
Labor force × $I(t \geq 2007)$			0.008*		0.008
			(0.004)		(0.004)
Time dummies		YES	YES	YES	YES
Fixed Effects		YES	YES	YES	YES
R^2		0.161	0.271	0.381	0.268
Observations		835	835	835	835

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) Includes only LAs that report an author count ≥ 1 in at least 1 year.

Table 15: **Academic Articles – Restricted Set of Related Articles:**
OLS (379 LA – 2000-2010)

		[I]	[II]	[III]	[IV]
Diamond × $I(t \geq 2007)$	25km	15.114*	14.372*	14.882*	14.395*
		(7.820)	(7.744)	(7.848)	(7.748)
	125km	-0.007	-0.333**	0.024	-0.307
		(0.192)	(0.135)	(0.278)	(0.205)
	175km	-0.358***	-0.109	-0.517**	-0.084
		(0.101)	(0.111)	(0.220)	(0.196)
Daresbury × $I(t \geq 2007)$	25km			0.730	0.545
				(0.935)	(0.845)
	125km			-0.098	0.013
				(0.284)	(0.223)
	175km			-0.319	-0.020
				(0.277)	(0.218)
%NVQ4 and above		0.030*	-0.0002		-0.002
		(0.016)	(0.012)		(0.012)
Labor force		0.093***	0.060***		0.060***
		(0.016)	(0.015)		(0.015)
%NVQ4 and above × $I(t \geq 2007)$			0.062***		0.063***
			(0.021)		(0.022)
Labor force × $I(t \geq 2007)$			0.008***		0.007***
			(0.002)		(0.002)
Time dummies		YES	YES	YES	YES
Fixed Effects		YES	YES	YES	YES
R^2		0.059	0.086	0.211	0.086
Observations		2,141	2,141	2,141	2,141

Notes:
1) Dependent variable is publication count by LA and year.
2) Robust standard errors clustered at LA-level.
3) All regressions include a constant.
4) 379 instead of 380 LAs because no covariates available for Isles of Scilly.